



Response to Summary of Issues

Deep Geological Repository (DGR) for Canada's Used Nuclear Fuel Project

March 2026

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Prepared by: Nuclear Waste Management Organization (NWMO)



NUCLEAR WASTE
MANAGEMENT
ORGANIZATION

SOCIÉTÉ DE GESTION
DES DÉCHETS
NUCLÉAIRES

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Response to Summary of Issues: Deep Geological Repository (DGR) for Canada's Used Nuclear Fuel Project

APM-REP-05000-0220-R000

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EXECUTIVE SUMMARY

On January 5, 2026, the NWMO submitted the Initial Project Description (IPD) to the Impact Assessment Agency of Canada, formally initiating the regulatory process for the Deep Geological Repository for Canada's Used Nuclear Fuel Project (the Project). The IPD outlines the project's purpose and need, the preliminary assessment of potential effects, and the NWMO's proposed approach to mitigation and monitoring.

This document is the NWMO's response to the Impact Assessment Agency of Canada's Summary of Issues (SOI) that was issued on February 16, 2026, following a 30-day comment period on the NWMO's Initial Project Description. In this submission, the NWMO provides information to address the consolidated concerns raised by Indigenous Peoples, the public, and government regarding the Deep Geological Repository (DGR) for Canada's Used Nuclear Fuel Project. The SOI and the NWMO's response will be used to inform the Agency's decision on whether to require an impact assessment for the proposed Project and to inform the impact statement guidelines should an assessment be required. This present document contains complete responses to the SOI issued by IAAC, including to concerns raised about transportation of used fuel. The NWMO recognizes the high level of interest regarding transportation and will be submitting an additional document to consolidate the information on the transportation of used fuel in a single location before the end of the 30-day period allocated for the proponent's response.

The purpose of the federal regulatory process is for the safety of the repository to be independently confirmed by regulators, including the Canadian Nuclear Safety Commission and the Impact Assessment Agency of Canada. The process follows strict rules and will look at how the deep geological repository could affect the environment, health, and Indigenous Rights before it can be approved. Engagement and relationship building with Indigenous Nations and communities, the public and interested parties is ongoing throughout the multi-year process, with opportunities to have input with the NWMO, the Impact Assessment Agency of Canada, and the Canadian Nuclear Safety Commission.

The NWMO's response to the SOI is available in English only.

RÉSUMÉ EXÉCUTIF

Le 5 janvier 2026, la Société de gestion des déchets nucléaires (SGDN) a soumis la Description initiale du projet à l'Agence d'évaluation d'impact du Canada, marquant le début officiel du processus réglementaire pour le Projet de dépôt géologique en profondeur (DGP) pour le combustible nucléaire irradié du Canada. La Description initiale du projet décrit l'objectif et la nécessité du projet. Elle fournit également une évaluation préliminaire des impacts potentiels et décrit l'approche proposée par la SGDN pour les atténuer et les surveiller.

Le présent document constitue la réponse de la SGDN au Sommaire des questions (SQ) de l'Agence d'évaluation d'impact du Canada, publié le 16 février 2026 à la suite d'une période de consultation de 30 jours sur la description initiale du projet de la SGDN. Dans cette soumission, la SGDN fournit des renseignements visant à répondre aux préoccupations consolidées des peuples autochtones, du public, et du gouvernement concernant le Projet de dépôt géologique en profondeur (DGP) pour le combustible nucléaire irradié du Canada. Le SQ et la réponse de la SGDN serviront à éclairer la décision de l'Agence quant à la nécessité d'une évaluation d'impact pour le projet proposé et à élaborer les lignes directrices relatives à l'étude d'impact, le cas échéant. Le présent document contient les réponses complètes à l'énoncé des intentions publié par l'Agence d'évaluation d'impact du Canada, notamment aux préoccupations soulevées concernant le transport du combustibles irradié. La SGDN reconnaît le vif intérêt suscité par le transport et soumettra un document supplémentaire regroupant l'information sur le transport des combustibles usés en un seul endroit avant la fin du délai de 30 jours imparti au promoteur pour y répondre.

L'objectif du processus réglementaire fédéral est de faire confirmer la sûreté du dépôt de manière indépendante par les organismes de réglementation, dont la Commission canadienne de sûreté nucléaire et l'Agence d'évaluation d'impact du Canada. Le processus obéit à des règles strictes et examinera l'incidence que pourrait avoir le dépôt géologique en profondeur sur l'environnement, la santé, les aspects socioéconomiques et les droits des Autochtones avant qu'une approbation puisse être accordée. La mobilisation et l'établissement de relations avec les collectivités autochtones, le public et les parties intéressées se poursuivront tout au long de ce processus pluriannuel, avec plusieurs occasions de formuler des commentaires auprès de la SGDN, de l'Agence d'évaluation d'impact du Canada et de la Commission canadienne de sûreté nucléaire.

La réponse de la SGDN au SQ est uniquement disponible en anglais.

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ACRONYMS AND ABBREVIATIONS

%	per cent
AECL	Atomic Energy of Canada Limited
ALARA	as low as reasonably achievable
ALWMS	Active Liquid Waste Management System
ASWMS	Active Solid Waste Management System
BMP	Best Management Practice(s)
CLC	Community Liaison Committees
CCME	Canadian Council of Ministers of the Environment
CNSC	Canadian Nuclear Safety Commission
COPC	Contaminant of Potential Concern
DFO	Fisheries and Oceans Canada
DGR	Deep Geological Repository
eDNA	Environmental Deoxyribonucleic Acid
ERMA	Excavated Rock Management Area
GBA Plus	Gender-Based Analysis Plus
HEPA	High efficiency particulate air filter
HHERA	Human Health and Ecological Risk Assessment
IA	Impact Assessment
IAA	<i>Impact Assessment Act</i>
IAAC	Impact Assessment Agency of Canada
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEMP	Independent Environmental Monitoring Program
IK	Indigenous Knowledge
ILW	Intermediate-level waste
IPD	Initial Project Description
km	kilometre
LLW	Low-level waste
LNT	Linear-Non-Threshold
m ³	cubic metre
mN	magnitude utilized in the Nuttli Scale

MNR	Ontario Ministry of Natural Resources
NBCC	National Building Code of Canada
NFWA	<i>Nuclear Fuel Waste Act</i>
NRCan	Natural Resources Canada
NSCA	<i>Nuclear Safety and Control Act</i>
NWMO	Nuclear Waste Management Organization
Project	Deep Geological Repository (DGR) for Canada's Used Nuclear Fuel Project
PSHA	Probability Seismic Hazard Assessment (PSHA)
RAAP	Regulatory Assessment and Approval Process
RAM	Radioactive Materials
REGDOC	Regulatory Document
RSOI	Response to Summary of Issues
SACC	Strategic Assessment of Climate Change
SCA	Safety and Control Area
SOI	Summary of Issues
SWH	Significant Wildlife Habitat
TBq	Terabecquerel
TLU	Traditional Land Use
UFC	Used Fuel Container
UFPP	Used Fuel Packaging Plant
UFTP	Used Fuel Transportation Package
UNSCEAR	United Nations Committee on the Effects of Atomic Radiation
WLON	Wabigoon Lake Ojibway Nation

1. Introduction

1.1 Introduction

Nuclear energy has powered our homes, workplaces, and communities for decades, providing reliable, carbon-free electricity that supports Canada's climate goals and energy security. It also creates used nuclear fuel that must be managed with care and foresight. Establishing a safe, permanent solution for this material is essential, both to honour our responsibility to protect people and the environment for generations to come and to ensure nuclear energy can continue contributing to a clean-energy future.

As described in the *Nuclear Fuel Waste Act* (NFWA), the Nuclear Waste Management Organization (NWMO) was established in 2002 by Canada's nuclear electricity producers to design and implement Canada's plan for the long-term management of used nuclear fuel. Over several years, the NWMO evaluated potential approaches, as required by the NFWA. Following a three-year dialogue with Indigenous Peoples and Canadians across the country, the NWMO recommended a path forward that reflected a shared expectation: that this generation must take responsibility for the waste created to meet its energy needs.

In 2007, the Government of Canada selected this approach as Canada's plan and directed the NWMO to implement it consistent with the NFWA. Called Adaptive Phased Management, it will contain and isolate used nuclear fuel in a deep geological repository using a multiple-barrier system. The Deep Geological Repository for Canada's Used Nuclear Fuel Project (the Project) is the enactment of that plan and continues to be grounded in the values, priorities and insights expressed through that national dialogue.

On November 28, 2024, the NWMO selected a site near the Township of Ignace, in the territory of Wabigoon Lake Ojibway Nation (WLON). This decision followed extensive technical studies, community engagement and people in the area confirming their willingness to move forward into the regulatory decision-making phase of the Project.

The Project is based on years of public input, international scientific consensus, Indigenous Knowledge and best practices from around the world. The NWMO is in the unique position of both being a leader in the field and being able to lean on internationally established best practices.

1.2 The Deep Geological Repository for Canada's Used Nuclear Fuel Project

The Project represents the portion of Adaptive Phased Management that is now undergoing an integrated federal impact assessment and nuclear licensing process.

Canada's deep geological repository (DGR) for used nuclear fuel will rely on a multiple-barrier system designed to safely contain and isolate used nuclear fuel over the very long term. This permanent solution eliminates the need for future generations to actively manage Canada's used nuclear fuel placed in the DGR.

The placement rooms of the DGR for the used fuel will be constructed between 500-800 metres underground. It will consist of a network of placement rooms constructed in stable, ancient rock that has remained largely unchanged for more than one billion years. While the DGR is intended as a permanent solution, early operational phases preserve flexibility. The licensing approach also considers retrieval contingencies if future policy or technological advances require them, consistent with the expectations of the Canadian Nuclear Safety Commission (CNSC).

Although current interim storage remains safe, it requires active management, which could require current storage infrastructure to be re-built every 50-100 years. A DGR is the internationally recognized permanent solution. Deep geology naturally isolates the DGR from the surface environment, reinforcing the strength of the multiple-barrier system. The entire purpose of the Project — the reason we are investing time, effort, and money to implement it — is to protect people and the environment, including water. This emphasis on water protection reflects what Indigenous Peoples and Canadians have consistently identified as essential to the wellbeing of their communities and future generations in connection with the long-term management of Canada's used nuclear fuel.

The Project has an approximately 160-year lifecycle which includes site preparation, construction, operations, and decommissioning and closure (including extended monitoring).

The Project has now entered the federal regulatory decision-making process. On January 5, 2026, the Impact Assessment Agency of Canada (IAAC) posted the NWMO's [Initial Project Description](#) (IPD; NWMO 2025a) to its registry, formally initiating this process. The IPD outlines the Project's purpose and need, the preliminary assessment of potential effects, and the NWMO's proposed approach to mitigation and monitoring.

The Integrated Impact Statement and Initial Licence will describe how the NWMO has assessed the Project's potential impacts on the environment and people, and clear mitigation measures in accordance with the federal *Impact Assessment Act* and its *Information and Management of Time Limits Regulations* as well as the *Nuclear Safety and Control Act*.

Throughout the lifecycle of the Project – from site preparation through construction, operations, and into decommissioning and closure (including extended monitoring) – the NWMO will monitor air, water, soil and, when applicable, blasting effects. This ongoing monitoring will follow CNSC licence requirements and federal guidance and will be updated as needed to reflect evolving conditions and regulatory expectations.

1.3 Summary of Issues for the Deep Geological Repository for Canada's Used Nuclear Fuel Project

The NWMO received the Summary of Issues from IAAC on Monday, February 16, 2026. The Summary of Issues outlines the key themes and questions raised by federal and provincial authorities, Indigenous Peoples and the public during the 30-day comment period on the IPD.

The NWMO is grateful to everyone who provided comments. The federal regulatory process is working as intended, with many people, communities and organizations showing an interest and taking the time to comment. Active public participation is an important part of the regulatory process and there will be multiple other opportunities in the future to provide input on the Project, including various documents.

2. Response to Summary of Issues Table

Table 1 below is the Summary of Issues received from IAAC. The NWMO has added the "NWMO Response" column as well as a response identifier number and provided a response to each key issue.

Table 2 in **Appendix A** contains Annex A of the Summary of Issues received from IAAC that provided additional comments, guidance and recommendations by IAAC and responses from the NWMO to this list. Table 3 in **Appendix B** contains comments received from the CNSC and responses from the NWMO to these comments.

Additionally, the following appendices are attached to inform the NWMO responses to transportation-related issues presented in IAAC's Summary of Issues:

- **Appendix C: Ignace Hosting Agreement** is an agreement between the NWMO and the Township of Ignace to inform responses NWMO-RSOI-25, NWMO-RSOI-27, NWMO-RSOI-28, Annex A NWMO-RSOI-77 and Annex A NWMO-RSOI-77;
- **Appendix D: Confidence in Transportation Package Performance** is a report attached to inform responses NWMO-RSOI-38, NWMO-RSOI-40, NWMO-RSOI-45, Annex A NWMO-RSOI-74 and CNSC-25;
- **Appendix E: Transportation Collision Data Analysis Report** is a report attached to inform responses NWMO-RSOI-38 and NWMO-RSOI-48;
- **Appendix F: Transportation Collision Mitigation Report** is a report attached to inform responses NWMO-RSOI-38 and NWMO-RSOI-48;
- **Appendix G: Preliminary Transportation Plan** is a report attached to inform responses NWMO-RSOI-38, NWMO-RSOI-39, NWMO-RSOI-42, NWMO-RSOI-44, NWMO-RSOI-45, NWMO-RSOI-48 and CNSC-25;
- **Appendix H: Transportation Planning Framework** is a report attached to inform responses NWMO-RSOI-39 and NWMO-RSOI-46;
- **Appendix I: Worker Dose Assessment** is a report attached to inform responses NWMO-RSOI-41 and CNSC-25;
- **Appendix J: Public Dose Assessment** is a report attached to inform responses NWMO-RSOI-41 and CNSC-25; and
- **Appendix K: Transport of Radioactive Materials in Canada in 2021 and 2022** is a report attached to inform response NWMO-RSOI-49.

Table 1: Response to Summary of Issues

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-1	Geology, geochemistry, and geological hazards	Suitability of host rock for long-term containment: Need for a detailed understanding of the rock formation at the proposed project site to determine if it is technically suitable to contain waste over the long term, based on its geological characteristics (e.g., rock type, permeability, structural stability, presence of faults and fractures).	The Nuclear Waste Management Organization's (NWMO) assessment of the suitability of the proposed Project site is based on site-specific results acquired to date, as well as regional information, intrinsic characteristics of the repository multiple barrier approach, and information gathered from similar projects in other countries. The site is within the Revell batholith, a rock formation with favourable characteristics, including a near-homogeneous granitoid composition. Site characterization activities were performed in accordance with Canadian Nuclear Safety Commission (CNSC) REGDOC-1.2.1 <i>Guidance on Deep Geological Repository Site Characterization</i>, while aligning with the licensing guidance and requirements of REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>. While a substantial amount of site characterization work has taken place to date in support of the site selection process, site characterization activities will continue for most of the Project lifecycle to inform and update key licensing submissions, including safety assessments, for future regulatory approvals and CNSC licences as the Project moves from the site preparation phase, to construction, and to operations. Example of continued site characterization activities include: • verification of information gathered and analyzed in earlier phases • establishment of an adequate baseline for future monitoring • information used in updates to the Project's post-closure safety case The NWMO's Confidence in Safety - Revell Site - 2023 Update Report (NWMO, 2023) is publicly available and contains detailed information on the characteristics of the rock formation. Key information relevant to geology, geochemistry and geological hazards are included below. The favourable characteristics of the geology at the proposed site include: • The Revell batholith formed about 2.7 billion years ago. It is approximately 40 km long, 15 km wide, and estimated to be about 3 km deep at the site. • Boreholes reaching up to one kilometre below surface confirm that this natural barrier system has the depth, breadth, and volume to isolate the repository from surface disturbances and changes caused by human activities and natural events. • The granitoid rocks beneath the site are similar to those of other crystalline rocks of the Canadian Shield, and also of the Fennoscandian Shield, where Finland and Sweden are implementing repositories. • Site-specific data provide confidence that the rock underlying the site can remove the heat generated by radioactive decay of the used fuel and withstand both natural stresses and thermal stresses. • The hydrogeological regime indicates low groundwater velocities in areas of low permeability rock mass away from potentially flowing fracture zones. With respect to the stability of the geosphere: • The Revell batholith is in the Canadian Shield at the heart of the North American continent. This is a stable, seismically quiet setting, far from tectonic plate boundaries and therefore is not prone to large earthquakes and recent volcanic activity. • There is no indication that the site location will experience extreme rates of erosion, uplift or subsidence that would significantly perturb the geosphere over the next million years. There is low likelihood of future human intrusion into the repository: • The site selected as the location for the Project is in Canadian Shield crystalline rock. Petroleum and coal resources are not encountered in these types of rocks.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
			- There are no indications of mineral resource potential at the site based on past exploration and current site borehole data. The site is amenable to additional and continued geological characterization: - The Revell batholith was expected to be a relatively homogenous rock mass. Data from the boreholes confirm the lithological homogeneity of the bedrock at the site with approximately 95% of the drill core recovered classified as biotite granodiorite-tonalite. - Borehole data indicates that the orientations of lineaments at the surface on a larger scale are also present in the orientations of fractures in the boreholes at a smaller scale. This understanding provides confidence in the ability to develop meaningful fracture network models on different spatial scales for the site. - Site-specific data and natural analogue information suggest that bedrock stresses can be safely managed, and a stable hydrogeochemical environment with favourable hydrogeological properties will be encountered, at the proposed repository depth beneath the site. These characteristics support a safe environment for the site preparation, construction, operations, and decommissioning and closure (including extended monitoring) phases and the long-term containment and isolation of the used fuel. Detailed description of geological characteristics will be included in a series of comprehensive geoscientific data and safety assessment reports. These reports are required as part of the initial licensing submission to fulfill CNSC requirements. Key submissions documenting the geological characteristics include: - Descriptive Geosphere Site Model - Geosynthesis Report - Post-Closure Safety Assessment - Safety Case
NWMO-RSOI-2	Geology, geochemistry, and geological hazards	Destabilization of geology and induced geological hazards: Concerns that destabilization of geology from project activities and components could cause induced disasters like earthquakes, landslides, slope failure, liquefaction, or volcanoes, and affect long-term containment of waste.	The site selected as the location for the Project is specifically chosen for its favorable geological properties. The Revell batholith is in the Canadian Shield at the heart of the North American continent. This is a stable, seismically quiet setting, far from tectonic plate boundaries and is not prone to large earthquakes or recent volcanic activity. There is no indication that the site location will experience extreme rates of erosion, uplift or subsidence that would impact the long-term containment of the used fuel over the next million years. The area comprises broadly rolling hills with low topographic relief underlain by competent Canadian Shield bedrock. The excavation activities are not expected to induce any natural disasters like earthquakes, landslides, or slope failure that will impact the long-term containment of waste. Granitic bedrock is exposed or covered by only a thin veneer of overburden across much of the Project site. There is no evidence of natural materials sensitive to liquefaction at the site. With respect to the long-term containment of waste: - In addition to the favourable geosphere, the repository includes a series of engineered barriers, in particular the fuel itself, which is a solid, the durable copper-coated containers and bentonite-clay based seals. Studies in Canada and around the world for several decades have provided a strong scientific basis for the safety of deep geological repositories designed around these barriers. - Natural analogues provide evidence that the engineered barrier materials, notably the copper, clay and uranium oxide, are durable over very long times under repository appropriate geological conditions. - The placement rooms, access tunnels, shafts and boreholes will all be backfilled and sealed at closure. The Post-Closure Safety Assessment evaluates the long-term performance of the entire barrier system, including the used fuel, and the engineered and natural barriers. Preliminary results will be reported or summarized in the Integrated Impact Statement and Safety Case submissions.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RS01-3	Geology, geochemistry, and geological hazards	Geochemical behaviour of rock material: Concern regarding the potential for excavated or exposed rock, or rock used for project-related purposes, to cause environmental effects through geochemical reactions such as acid rock drainage and metal leaching.	Site characterization activities for the Project have been and continue to be performed in accordance with Canadian Nuclear Safety Commission (CNSC) REGDOC-1.2.1 <i>Guidance on Deep Geological Repository Site Characterization</i>, while aligning with the licensing guidance and requirements of CNSC REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>. The Excavated Rock Management Area (ERMA) will be designed and monitored to provide appropriate environmental protection as required to avoid adverse environmental effects. As stated in Initial Project Description (IPD) Section 14, the NWMO has initiated geochemical testing of rock core samples for the purposes of geochemical characterization (i.e., the potential for acid rock drainage and metal leaching) to support preliminary technical studies related to excavated rock management. The relatively homogenous crystalline granitic rock of the Revell batholith would be considered to have a generally low potential for mineralization most commonly associated with metal leaching and acid rock drainage. Geochemical baseline studies are continuing, but results to date generally support this deduction and indicate that the rock is non-acid generating and non-metal leaching. Results of the geochemistry baseline study completed to date indicate that the rock is non-acid generating. Waste rock static testing on the Project site included 105 samples taken from drill core that had weakly alkaline test results ($> \text{pH } 9.5$) and sulphide sulphur content that was below laboratory analytical detection limits in most samples. When observed above detection limits, sulphide sulphur content was consistently low ($<0.08 \text{ wt.}\%$) in the predominant rock type (tonalite) and slightly higher but still low ($<0.16\%$) in low abundance rock types (amphibolite and diabase). Further evaluation of the data on the basis of industry standard guidance (MEND, 2009) indicated that the tested rock was expected to have excess neutralization potential over acid potential, sufficient to limit the potential for acid rock drainage in all but a few samples. These few samples had an uncertain potential for acid generation based on the range of tests completed. Based on the low sulphide content and expected low sulphide oxidation rates in a small proportion of the rock, net acidic drainage conditions are not expected and additional characterization is continuing to confirm. The results of screening level leachate testing on rock samples indicated a low potential for neutral metal leaching from rock samples, with only aluminum consistently identified above comparative reference water quality values. The screening level tests do not simulate field leaching conditions and the elevated aluminum values for these materials could be due to test conditions that do not reflect future field leaching conditions. Kinetic studies on selected rock samples are underway to evaluate reaction/weathering rates and to confirm the low acid rock drainage and metal leaching potential of future underground development rock. Assessment is also underway of the metal leaching and acid rock drainage potential of overburden materials that may be excavated in site development activities. Reporting of the overburden and kinetic studies will be included as part of the Integrated Impact Statement. At this time, the geochemical testing program to support preliminary technical studies related to excavated rock management is underway as described above. Both existing knowledge of the Revell batholith geology and results to date are not anticipated to demonstrate that the rock is potentially acid generating or possess metal leaching potential. The geochemical study results, including the site-specific material characteristics for the Project, are also being incorporated into site water quality and air dispersion models being developed to inform the Integrated Impact Statement. Should any concerns be identified, appropriate mitigation measures will be proposed in the Integrated Impact Statement. In keeping with best management practices and CNSC licensing requirements, geochemical studies will continue and be expanded if necessary, based on results and continued Project development planning. These studies will inform a geochemical assessment of the Project, including excavated or exposed rock and overburden materials, or rock/aggregate materials used for Project-related purposes. The assessment results, including any direct and indirect potential effects on the environment or Indigenous Nations and communities, will be a part of the Integrated Impact Statement, and where applicable, in the Initial Licence Application. This work will include assessing all excavated or exposed rock and overburden materials, or rock/aggregate materials used for Project-related purposes. All best practices proposed to be used for the Project to avoid or reduce potential effects of acid generation / metal leaching, will be described in the Integrated Impact Statement, including standard mitigation measures described by the Impact Assessment Agency of Canada (IAAC, 2026) to mitigate activities that disturb materials that may be acid generating / metal leaching.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-4	Radiological Conditions	Radiological effects to the environment: Concern regarding potential radiological effects to the terrestrial, aquatic and atmospheric environment.	During operations, decommissioning and closure, the potential for radiation releases will be rigorously managed under the Canadian Nuclear Safety Commission (CNSC) regulatory oversight and licensing regime. Effects, mitigation measures, and monitoring requirements for these phases are comparable to those assessed for the Ontario Power Generation Deep Geologic Repository Project and Atomic Energy of Canada Limited Nuclear Fuel Waste Management and Disposal Concept. In both cases, federal assessments concluded that, with mitigation, significant adverse effects were not expected, and deep geological disposal was identified as the preferred method for safely isolating radioactive waste. Based on extensive site investigations and technical studies undertaken since 2010, the NWMO has confidence that the selected site has characteristics suitable for the safe containment and isolation of used nuclear fuel. Adverse radiological effects are not anticipated. Given the nature of the facility operations and the very small quantities of radiological contaminants that are expected to be released to the environment, calculated radiological exposures to the public and sensitive populations are expected to be a very small fraction of the acceptable public dose limits. As stated in the IPD Section 19, the NWMO anticipates limited adverse residual effects to the terrestrial, aquatic and atmospheric environment, including from radiological effects. Project activities will be managed through a combination of best management practices, environmental design features and mitigation measures. This conclusion will be rigorously tested and confirmed through the CNSC graded, lifecycle approach to licensing. The level of detail and robustness of assessments progressively increases at each licensing step. The initial licence sought will be limited to site preparation activities. A separate and more detailed safety case will be required to support a licence to construct, including confirmation of the safety of underground construction methods and blasting activities, and a further licence will be required before any operations involving emplacement of used nuclear fuel could occur. At each stage, regulatory approval must be obtained before the Project may proceed. Per CNSC REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>, the NWMO is required to prepare and submit several studies and assessments that quantify and discuss potential radiological effects on human health and the environment. The studies include, but are not limited to: • Pre-Closure Safety Analysis: Evaluates whether the repository and associated surface facilities can safely protect humans and the environment from the hazards associated with the used fuel (both radiological and chemical elements associated with the nuclear substances) during operation, under normal operating conditions, and in the case of abnormal events and accidents. This analysis is developed in accordance with CNSC REGDOC-2.4.4 <i>Safety Analysis for Class IB Nuclear Facilities</i>. • Post-Closure Safety Assessment: Evaluates the long-term evolution of the entire waste management system, including the waste, engineered and natural barriers. Assesses impacts to human health and the environment over an assessment timeframe of 1 million years. The assessment is developed in accordance with CNSC REGDOC-2.11.1 Volume III, <i>Safety Case for the Disposal of Radioactive Waste</i>. • Human Health and Ecological Risk Assessment (HHERA): Estimates the nature and probability of adverse health effects in humans and assesses potential risks to the ecological health from contaminated environmental media. Many activities performed to support the integrated impact assessment process are continued throughout the entire lifecycle of the project, per the licence requirements and conditions. For example, the collection of site characterization data continues, which supports the safety case, and provides real data in which to compare the initial effects assessments and predictions. The assessment of risk to the environment and humans also continues through periodic Environmental Risk Assessments, which are required for each licensing stage. Through the Environmental Protection Program, environmental monitoring activities are required to continue for the duration of the licence and all subsequent licensing phases.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-5	Radiological Conditions	Radiological contamination of water: Concern regarding potential radiological effects to water, including contamination of local watersheds, drinking water, groundwater systems, and aquifers, as well as possible transboundary effects to shared water bodies.	Please see the NWMO response in this document to NWMO-RSOI-10 and NWMO-RSOI-15 regarding concerns of potential changes to water quality and quantity (both surface water and groundwater) from the Project. Based on extensive site investigations and technical studies undertaken since 2010, the NWMO has confidence that the selected site has characteristics suitable for the safe containment and isolation of used nuclear fuel. Adverse effects to humans or the environment from changes to water quality from potential release of radiation or other contaminants of potential concern from the Project are not anticipated. As stated in IPD Section 19, the NWMO anticipates limited adverse residual effects to water from radiological effects, such as contamination of local watersheds, drinking water, groundwater systems, and aquifers. No residual transboundary effects to shared water bodies are expected. Project activities will be managed through a combination of best management practices, environmental design features, and mitigation measures. As part of the Integrated Impact Statement and Initial Licence Application, the NWMO is required to assess potential radiological and non-radiological effects on water, including the consideration of accidents and malfunctions that could affect surface water and groundwater. For the Project, this includes evaluating how Project activities could interact with water pathways and what those interactions could mean for downstream users, including fish, wildlife, members of the public and Indigenous Nations and communities. As outlined in the IPD, the detailed assessment of potential effects to water, including the determination of the appropriate study areas for the impact assessment, will be undertaken through the integrated impact assessment process. Effects assessment methodologies will be developed on a component-specific basis and informed by the Impact Assessment Agency of Canada's Tailored Impact Statement Guidelines, as well as relevant Canadian Nuclear Safety Commission (CNSC) guidance, including REGDOC-1.2.1 (<i>Guidance on Deep Geological Repository Site Characterization</i>), REGDOC-2.9.1 (<i>Environmental Protection: Environmental Principles, Assessments and Protection Measures</i>), and REGDOC-3.5.3 (<i>Regulatory Fundamentals</i>). Consistent with the CNSC's graded approach to licensing, the level of detail and analysis will be commensurate with the Project phase and associated risks. Protecting water quality is a core design priority for the Project. The Project includes integrated water management systems to collect, manage, and treat water associated with site activities, with any contact water or discharge managed in accordance with regulatory requirements, including any requirements of the Wabigoon Lake Ojibway Nation (WLON) Regulatory Assessment and Approval Process (RAAP). Potential accident and malfunction scenarios will be assessed as part of the regulatory process to confirm that mitigation, and monitoring measures are in place to protect water resources. Robust regulatory oversight applies throughout the Project lifecycle, including required environmental and effluent monitoring programs that are routinely assessed and reassessed by the CNSC to ensure risks remain well below levels that could pose harm to people or the environment. The NWMO's Environmental Protection Program, which includes an adaptive management component, will comply with CNSC licensing and federal/provincial permitting requirements. The NWMO will implement a Project-specific Environmental Monitoring Plan that includes compliance monitoring of changes to water quality and quantity as required, in accordance with CNSC licence requirements, and RAAP conditions (if applicable). Monitoring programs will be developed and using adaptive management practices will be refined over time, as the Project progresses through the regulatory processes informed by engagement with The Township of Ignace, the Anishinaabe peoples of WLON and other potentially affected Indigenous Nations and communities.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-6	Radiological Conditions	Radiological effects on health: Concern regarding potential worker and public exposures to radiation for all project phases. This includes radiation exposures to nearby communities and sensitive populations.	A Human Health and Ecological Risk Assessment (HERA) will be completed to inform Canadian Nuclear Safety Commission (CNSC) initial licensing and the Impact Statement All work where the potential for radiation exposure exists will be performed in accordance with the Radiation Protection Program. Radiation work plans are used to help keep doses to workers as low as reasonably achievable, with administrative and action levels set to ensure compliance with the <i>Radiation Protection Regulations</i>. The site preparation and construction phases of the Project are expected to occur over a period of about 13 years. During these Project phases, there will not be any used nuclear fuel at the site. Receipt of used fuel at the Project site is expected to begin in 2043, with commencement of the operations phase of the Project. There is a potential for some Naturally Occurring Radioactive Material (NORM) to be present on-site during the site preparation and construction activities, but the potential for radiological health effects or risks from these materials is very low. Used fuel arrives at the Project site contained in a certified transport package. The packaging itself provides protection against radiation and contains the material, even in the event of accidents, minimizing the need for special handling or administrative controls. Used fuel is removed from the transport package in a specialized hot-cell facility, where the fuel is remotely handled to limit radiation exposure to workers. The used fuel continues to be handled in a series of hot-cells where it is packaged into used fuel containers and transferred to the underground repository for final emplacement. Environmental releases of radiological contaminants are regulated by the CNSC and are managed through the implementation of environmental protection measures within the site Environmental Management System, including programs for the control and monitoring of effluents and emissions. Releases of radiological material are expected to be minor and are primarily a result of operations at the Used Fuel Packaging Plant. There are expected to be small quantities of fugitive airborne releases from the hot cells, which will pass through HEPA filters to remove over 99.97% of particulates before released to a stack. There will be an Active Liquid Waste Management System for treatment of water contaminated with radionuclides from operations at the Used Fuel Packaging Plant. Active wastewater is processed through a treatment system comprised of cartridge filters, an activated carbon filter, and ion exchange resins. Effluent is treated to the required discharge limits prior to release to the ponds. Similar Active Liquid Waste Management Systems have been operated successfully for many years at licensed nuclear facilities in Canada. Contact water will be managed, monitored, and if required, treated, prior to discharge to the receiving environment. Per CNSC REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>, the NWMO is required to prepare and submit several studies and assessments that quantify and discuss potential radiological effects on human health and the environment. The studies include, but are not limited to: <u>Pre-Closure Safety Analysis:</u> Evaluates whether the repository and associated surface facilities can safely protect humans and the environment from the hazards associated with the used fuel (both radiological and chemical elements associated with the nuclear substances) during operation, under normal operating conditions, and in case of abnormal events and accidents. This analysis is developed in accordance with CNSC REGDOC-2.4.4 <i>Safety Analysis for Class IB Nuclear Facilities</i>. <u>Post-Closure Safety Assessment:</u> Evaluates the long-term evolution of the entire waste management system, including the waste, engineered and natural barriers. Assesses potential impacts to human health and the environment over an assessment timeframe of 1 million years. The assessment is developed in accordance with REGDOC-2.11.1 Volume III, <i>Safety Case for the Disposal of Radioactive Waste</i>.

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			<u>HHERA:</u> Estimates the nature and probability of adverse health effects in humans and assesses potential risks to the ecological health from contaminated environmental media. It is through the HHERA that potential radiation exposures to nearby communities and sensitive populations is assessed and evaluated. Given the nature of the facility operations and the very small quantities of radiological contaminants that are expected to be released to the environment, calculated radiological exposures to the public and sensitive populations are expected to be a very small fraction of the public dose limits. The Integrated Impact Statement will summarize and present the results of the HHERA.
NWMO-RSOI-7	Radiological Conditions	Duration of radioactivity: Concern regarding the types and amounts of radiological releases, and the duration fuel will remain radioactive.	The purpose of the Project is to provide a permanent, safe, and environmentally responsible solution for the management of the used nuclear fuel. The Project will safely contain and isolate the used fuel bundles in a stable geological formation, eliminating the need for ongoing active management and protecting people and the environment for generations to come. Environmental releases of radiological contaminants are regulated by the Canadian Nuclear Safety Commission (CNSC) and are managed through the implementation of environmental protection measures within the site Environmental Management System, including programs for the control and monitoring of effluents and emissions. Releases are understood and evaluated, and will be controlled, monitored, and regulated through the application of Release Limits. <u>Waste generated during Project operations & decommissioning</u> During operations (estimated year 2043 and beyond) at the Used Fuel Packaging Plant (UFPP) radioactive waste may be generated due to airborne release of volatile fission products from fuel bundles. These releases will be circulated through the active ventilation system and particulates will be caught by filters; some radionuclides however may deposit onto equipment surfaces within the UFPP. These deposited radionuclides will be captured by (liquid or solid based) decontamination activities, or remain as residual contamination on UFPP equipment, which will in turn be considered waste. Active solid waste will be produced during UFPP operations such as the receipt, inspection and packaging of the used fuel bundles, decontamination activities and treatment of active liquid waste. The active solid waste will be collected, sorted, and packaged in the UFPP by the Active Solid Waste Management System (ASWMS) and then transferred to a surface interim waste storage facility. The vast majority of the waste by volume will be low-level radioactive waste (LLW) solid items that will be volume reduced to minimize storage infrastructure needs during interim storage. The remaining waste material, some LLW and a small quantity of intermediate-level radioactive waste will be placed directly into storage containers for interim storage. Most of the radioactivity will be produced from decontamination activities within the UFPP. The Active Liquid Waste Management System (ALWMS) will treat water that has been used during decontamination activities and will be captured by ion exchange resins and filters. <u>The following paragraph includes preliminary estimates of LLW and ILW generation during operations. The estimates are subject to change as design and operation plans mature.</u> Average annual arisings of operation and maintenance LLW and ILW are estimated to include 60 m³ of non-processible LLW, 270 m³ of compacted LLW and 0.37 m³ of Ion Exchange (IX) resins. The total Project LLW and ILW is estimated to comprise ~16,500 m³ of raw waste with an assumed packaged volume of ~36,400 m³ (excluding wastes arising during decommissioning). There is a potential for LLW and ILW to be generated during the decommissioning phase, primarily from the dismantling and decommissioning of the UFPP. Industry best practices will be used to minimize radioactive waste generation during decommissioning activities.

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			<u>The used fuel inventory</u> The Project is intended to contain and isolate up to 5.9 million used fuel bundles, as outlined in the NWMO's Nuclear Fuel Waste Projections Report - 2024 Update (NWMO, 2024). This projection is based on published refurbishment and life-extension plans for Ontario Power Generation's Darlington and Bruce reactors, and the continued operation of Pickering A reactors (until end of 2024) and Pickering B reactors (until end of 2026), and on the NWMO's assumptions used for planning purposes. The radioactivity of used fuel decreases with time and drops significantly within the first thousand years. The remaining amount of radioactivity after one million years is similar to that in an equivalent amount of natural uranium ore.
NWMO-RSOI-8	Radiological Conditions	Radiological effects to wildlife: Concern regarding potential radiological effects on wildlife, including impacts related to bioaccumulation and migration	A Human Health and Ecological Risk Assessment (HHERA) will be completed to inform the Integrated Impact Statement and Initial Licensing Application. Based on extensive site investigations and technical studies undertaken by the NWMO since 2010, the NWMO has confidence that the selected site has characteristics suitable for the safe containment and isolation of used nuclear fuel. Adverse effects to humans or the environment, including wildlife, from potential release of radiation or other contaminants of potential concern from the Project are not anticipated. The Canadian Nuclear Safety Commission (CNSC) licensing process mandates rigorous assessments, including the HHERA that evaluate potential exposure pathways, dose modelling, and mitigation strategies aligned with CNSC's Safety and Control Areas (SCAs), such as Radiation Protection, Conventional Health and Safety, and Environmental Protection. With the implementation of environmental design features, mitigation and protection measures, radiological effects on wildlife are unlikely to occur; this will be fully assessed in the integrated Impact Statement. The effectiveness of proposed environmental design features, mitigation and protection measures are well-documented and widely accepted across the industry. Ecological components and wildlife receptors will be selected for the HHERA based on feedback and engagement from potentially affected Indigenous Nations and communities and the public. Both radiological and contaminants of potential concern (including the potential for bioaccumulation) pathways via air, soil, and water will be conservatively modelled as part of the HHERA to predict potential effects to ecological receptors, such as wildlife, based on a calculation of dose and risk. The HHERA will be reviewed by the CNSC under the <i>Nuclear Safety and Control Act</i> and CNSC REGDOC-2.9.1 and will be routinely updated with data collected as the Project progresses to confirm the effectiveness of mitigation measures. The frequency of HHERA update will be every five years throughout the Project's lifespan. The NWMO's environmental monitoring program will be implemented throughout the lifespan of the Project and include monitoring activities to verify that terrestrial wildlife and wildlife habitat is performing as intended and effects from potential direct or indirect effects are minimized. This compliance monitoring will be regulated by the lifecycle regulator to verify that the conditions of the CNSC's approval are met.
NWMO-RSOI-9	Groundwater and Surface Water	Water usage: Concerns regarding potential effects of project-related water usage during project construction and operation on local groundwater and surface water systems, including uncertainties about water sourcing, effects to watercourses and local drinking water sources, and overall environmental impacts.	Effects to hydrology and surface water quality will be studied as part of the Integrated Impact Statement and Initial Licence Application. The water taking and discharge locations for the Project will be evaluated as the Project progresses. The NWMO intends to carry multiple options into the Integrated Impact Statement phase such that decisions on water management for all phases of the Project, including water taking and discharge locations during site preparation, construction and operations, can be informed by engagement with Wabigoon Lake Ojibway Nation (WLON) and other potentially affected Indigenous Nations and communities. The NWMO will also complete groundwater and surface water modelling to inform water management decisions for the Project that are carried forward into the effects assessment. Proposed water taking and discharge locations will be presented in the Integrated Impact Statement and Initial Licence engagement with the Anishinaabe Nation of WLON and other potentially affected Indigenous Nations and communities. The results of groundwater and surface water modelling will optimize Project-specific environmental design features, site-specific mitigation measures and monitoring requirements. This work will inform the groundwater and surface water effects assessments and the NWMO's Environmental Monitoring Program that will be included in the Integrated Impact Statement and Initial Licence application. The NWMO will only proceed with submitting the Integrated Impact Statement if the effects assessment concludes that there are no significant adverse effects to watercourses, local drinking water sources, or the environment.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-10	Groundwater and Surface Water	Potential and cumulative effects on water: Concern regarding how potential and cumulative project effects may impact water quality and quantity, including discharge rates and water levels, hydrological regimes, and associated ecosystem components such as migratory bird habitat and fish habitat within the project area.	As outlined in the IPD, the detailed assessment of potential effects to water, including the identification of appropriate study areas for the impact assessment, will be undertaken through the integrated impact assessment process. Furthermore, the Impact Assessment will consider not only the potential effects of individual Project activities, as defined in the IPD, but also how any residual effects may interact over time and in combination with other past future activities, in accordance with Impact Assessment Agency of Canada (IAAC) guidance. Based on IAAC guidance documents, the historical context of existing conditions will be considered in the characterization of residual Project effects. If adverse residual effects to water quality and quantity and associated ecosystem components from the Project are predicted, a cumulative effects assessment will be completed. Also described in the IPD, the Project will involve localized land disturbance at the Project site associated with construction, operations, safety, and security requirements. With the application of established design features and mitigation measures, and based on studies completed to date, the Project is anticipated to result in limited residual adverse effects to surface water, groundwater, and other ecosystem components that support migratory bird habitat and fish habitat within the Project area. Project activities will be managed through a combination of best management practices, environmental design features and mitigation measures, including the implementation of a water management system that includes the following: • In accordance with the requirements of Canadian Nuclear Safety Commission (CNSC) REGDOC-2.9.2, the NWMO will complete a best available and economically achievable assessment for mitigation measures to control environmental releases and develop corresponding environmental action levels for liquid effluent releases • Adequate storage capacity to manage, treat and complete controlled release (including the consideration of climate change scenarios) • All contact water will be collected, monitored and treated, if necessary, prior to release to the environment • Treated effluent and sewage discharges will comply with applicable water quality standards • Sediment release during in-water construction will be minimized through isolation techniques and erosion control measures • Best management practices for sediment and erosion control measures • Scheduling land disturbance activities to avoid the spring freshet period to reduce the potential of erosion, sedimentation, and contamination of surface water. Proposed measures in the Impact Statement will also include, where feasible, those recommended by IAAC in its List of Standard Mitigation Measures, including: measures to avoid or reduce potential effects to fish and fish habitat and migratory birds (IAAC, 20026). Furthermore, the Project will be required to mitigate changes in surface water levels to avoid the harmful alteration, disruption or destruction of fish habitat, and if required, an authorization under the <i>Fisheries Act</i> will be submitted by the NWMO to Fisheries and Oceans Canada (DFO). Hydrology and water quality modelling, including the completion of an integrated site-wide water balance, surface and groundwater modelling, and geosphere model will be included in the Integrated Impact Statement. The results of this modelling will inform the optimization of Project-specific environmental design features, site-specific mitigation measures and monitoring requirements, including the effluent and emissions control monitoring plan and surface water aspects of the environmental monitoring program. Hydrology and water quality model results will also inform the Human Health and Ecological Risk Assessment (HHERA) using conservative assumptions, such as low detection limits for contaminants of potential concern (COPC), as required for the NWMO's Integrated Impact Statement and Initial Licence Application. In accordance with the <i>Nuclear Safety and Control Act</i> (NSCA) and CNSC REGDOC-2.9.1, the HHERA will be reviewed by the CNSC to demonstrate that proposed protection measures reduce effects as low as reasonably achievable. Ecological receptors, such as fish and migratory birds, will be included in the HHERA to predict the exposure to COPCs based on a calculation of dose and risk. It is important to note that chemicals such as mercury are not used as part of the Project or Project activities. The NWMO is, however, aware that certain construction and land disturbance activities can influence biogeochemical conditions in the environment that may affect methylmercury production, including interactions with aquatic systems and wild rice. These considerations are being examined through ongoing studies, and findings will be reported in the Integrated Impact Statement and Initial Licence Application, including through HHERAs.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-11	Terrestrial, riparian and wetland environments	Construction effects to terrestrial, riparian and wetland environments: Concern for potential adverse effects on terrestrial vegetation, riparian areas, and wetland environments from construction activities (e.g., site clearing, in water works, altered drainage, runoff, water withdrawals, and treated effluent discharge).	This will be studied as part of the integrated impact assessment process. Regulatory oversight under federal and provincial frameworks and proposed mitigation and protection measures presented in the IPD are expected to effectively avoid or minimize potential effects on terrestrial vegetation, riparian areas, and wetland environments from site preparation and construction phase activities. Site preparation and construction phase activities will be planned and executed to avoid or minimize effects to terrestrial vegetation, riparian areas, and wetland environments by following best management practices (BMPs) for environmental design features and mitigation measures (see Table 19.4 of the IPD – “Pathways of Change Screening for Intermediate and Valued Components” for more information on proposed environmental design features and mitigation measures to avoid or reduce potential effects to terrestrial, riparian and wetland environments). The effectiveness of these mitigation strategies is well-established and supported by industry experience and regulatory guidance. Proposed measures will also consider those recommended by the Impact Assessment Agency of Canada (IAAC) in its List of Standard Mitigation Measures, as feasible, including measures to mitigate general activities that disturb soil and sediment (IAAC, 2026). An assessment of potential effects from site preparation and construction activities will be presented in the Integrated Impact Statement. The assessment will include consideration of pathways of change to vegetation, riparian areas, and wetlands from water taking and discharge activities based on the Project's water needs for all phases of the Project. Hydrology and water quality modelling, including the completion of an integrated site-wide water balance, geosphere model, and water quality modelling will also be included in the Integrated Impact Statement and Initial Licence Application. The results of this modelling may inform optimization of environmental design features, site-specific mitigation measures and monitoring requirements, including effluent and emissions control monitoring Project. Hydrogeological, hydrological, and water quality modelling will be completed to quantify changes in groundwater and surface water quantity and quality. The results of these modelling activities will be presented in the Integrated Impact Statement. Modelling results may also inform optimizations to environmental design features, refine site-specific mitigation measures and define monitoring requirements, including those that will be presented in the Effluent and Emissions Control and Monitoring Plan, and Groundwater Protection and Monitoring Plan that will be included as part of the NWMO's Initial Licence Application. Through ongoing engagement, the Integrated Impact Statement will consider shared values and perspectives of Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities in the assessment of potential Project effects on terrestrial vegetation, riparian areas, and wetland environments from construction activities, including the identification of proposed mitigation measures.
NWMO-RSOI-12	Terrestrial, riparian and wetland environments	Reclamation: Concern regarding how the area will be reclaimed after the DGR is sealed and decommissioned	A preliminary decommissioning plan and a full lifecycle closure and decommissioning plan will be submitted as part of the Integrated Impact Statement and Initial Licence Application in alignment with Canadian Nuclear Safety Commission (CNSC) REGDOC 2.11.2, <i>Waste Management: Decommissioning</i>. Furthermore, as part of the initial licence application, the NWMO is required to demonstrate that the site evaluation process has appropriately considered future decommissioning in the planning for the nuclear facility and has adequately considered end-of-life decommissioning. Prior to decommissioning, the NWMO will implement progressive reclamation and revegetation of disturbed areas no longer required. This is in alignment with the Impact Assessment Agency of Canada's (IAAC) list of Standard Mitigation Measures for ground disturbing activities that may adversely affect current use of lands and resources for traditional purposes (IAAC, 2026). A detailed decommissioning plan will be submitted to the CNSC as part of the Project's decommissioning phase to outline how the Project will be sealed and decommissioned and how the Project area will be reclaimed. This detailed decommissioning plan, including future land use, will include information on terrestrial, riparian, and wetland environments and be informed through engagement with Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities, as well as best management practices at the time. Revision of future decommissioning and closure plans will be completed to reflect experience gained during the extended monitoring phase, as well as regulatory or technology updates.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RS01-13	Terrestrial Wildlife and their Habitat	Wildlife: Concerns regarding potential adverse effects of the project on local wildlife and habitat (including amphibians and reptiles). Need more information on levels of disturbance, displacement, or harm	This will be studied as part of the integrated impact assessment process. As stated in IPD Section 19, through a combination of regulatory controls, best management practices, environmental design features and known effective mitigation measures, the NWMO anticipates limited adverse environmental effects on terrestrial wildlife and wildlife habitat. Further assessment of potential effects on terrestrial wildlife and wildlife habitat, including potential disturbance, displacement or harm, will be completed in the Integrated Impact Statement to meet licensing requirements under the <i>Nuclear Safety and Control Act</i> (NSCA) and to inform provincial and federal permitting requirements. The NWMO is completing additional baseline studies of terrestrial wildlife and wildlife habitat to inform this assessment, including studies on amphibians and reptiles. Through ongoing engagement, the Integrated Impact Statement will consider shared values and perspectives of Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations communities in the assessment of potential Project effects on wildlife and wildlife habitat, including the identification of proposed mitigation measures.
NWMO-RS01-14	Species at risk and their habitat	Species at risk: Concern regarding insufficient information on species at risk and their habitats in the area surrounding the project, including information on direct and indirect pathways of effects.	This will be studied as part of the integrated impact assessment process. As stated in IPD Section 19, the NWMO anticipates limited adverse environmental effects on species at risk and their habitats. Further assessment of potential direct and indirect effects from the Project on species at risk and their habitat will be completed in the Integrated Impact Statement. The NWMO will meet licensing requirements under the <i>Nuclear Safety and Control Act</i> (NSCA) and all provincial and federal permitting requirements (i.e., provincial and federal <i>Species at Risk Act</i>, as applicable based on evolving species at risk legislation). The NWMO is completing additional baseline studies of species at risk and their habitat in the Project area to inform this assessment. Studies to date have focused on collating existing data on species presence and known important habitats, using desktop sources and collecting foundational habitat information through terrestrial ecosystem mapping, Aquatic Habitat Mapping, Environmental Deoxyribonucleic Acid (eDNA) metabarcoding studies in aquatic habitats, and opportunistic identification of provincial candidate significant wildlife habitat (SWH), alongside terrestrial ecosystem mapping. Further field studies will be conducted by the NWMO to verify the presence and distribution of species at risk throughout the Project site and surrounding area. Through ongoing engagement, the Integrated Impact Statement will consider shared values and perspectives of Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities in the assessment of potential Project effects on species at risk, including the further identification of potential effect pathways and proposed mitigation measures.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-15	Fish and Fish Habitat	Fish and Fish Habitat: Concerns regarding potential effects of the project on fish and fish habitat, including resulting from changes in water quality and quantity to groundwater and surface water flows.	This will be studied as part of the integrated impact assessment process. Please see response in this document to NWMO-RSOI-10 for additional information as to how the NWMO will address potential Project and cumulative effects on water quality and quantity. Project activities, including underground development and runoff and seepage from surface facilities, have the potential to change existing groundwater levels (quantity) and groundwater quality. Site clearing, blasting, construction of Project components, altered site drainage, runoff, water withdrawal and discharge of treated effluent have the potential to change existing hydrology and surface water flow quality and quantity. Some changes to groundwater and surface water flows will occur from the Project, potentially affecting fish and fish habitat. See IPD Figures 14.6 and 14.7 showing watersheds/flow directions and waterbodies/watercourses in and surrounding the Project area. The NWMO is completing multiple models to understand and predict changes in surface and groundwater quality and quantity, and the presence and changes in flow of both surface and groundwater at and surrounding the Project site. This modeling will inform the understanding of potential effects on fish and fish habitat, potential optimization of Project design, refinement of proposed mitigation measures, and future follow-up and compliance monitoring. The NWMO will implement best management practices, environmental design features and mitigation measures, including known effective standard mitigation measures to avoid or reduce potential effect to fish and fish habitat. Appropriate and effective mitigation measures will be described in the Integrated Impact Statement to avoid or minimize potential changes to surface and groundwater flows that could adversely affect fish and fish habitat (see IPD Table 3-1 for a preliminary list of proposed mitigation measures). Key design features and measures include the: • Safety of the Project, the multiple-barrier storage system, and the characteristic of the surrounding rock formation as a natural barrier (i.e., geosphere) with low groundwater flow • Surface infrastructures, designed where possible to avoid environmentally sensitive features (e.g., fish habitat) • Proposed integrated water management system for the site to manage water from the underground and surface facilities (i.e., collects, transfers, treats, discharges and monitors all contact water from surface and underground facilities). This system includes pumps, collection ponds, treatment plants, and controlled discharge infrastructure instrumentation so that water released to the environment meets regulatory standards for the receiving environment • Design, maintenance, and monitoring of the underground dewatering system to manage groundwater inflows. • Application of Fisheries and Oceans Canada's (DFO) Policy for Applying Measures to Offset Adverse Effects on Fish and Fish Habitat Under the <i>Fisheries Act</i> to minimize potential adverse effects on aquatic resources. • Implementation of best management practices and known effective mitigation measures. The effectiveness of these mitigation strategies is well-established and supported by industry experience and regulatory guidance • Adherence to all permitting requirements, DFO <i>Fisheries Act</i> Authorization, any required fish habitat offsetting plan in consultation with DFO and engagement with Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities. Given the anticipated effectiveness of mitigation, regulatory controls, and proven established best practices, the NWMO anticipates limited adverse effects to fish and fish habitat. Further assessment of potential effects of the Project on fish and fish habitat will be completed to support the Impact Statement, meet licensing requirements under the <i>Nuclear Safety and Control Act</i> (NSCA), and inform provincial permitting requirements. Through ongoing engagement, the Integrated Impact Statement will consider shared values and perspectives of Wabigoon Lake Ojibway Nation (WLON) and other potentially affected Indigenous Nations and communities in the assessment of potential direct and indirect Project effects on fish and fish habitat, including the identification of proposed mitigation measures. Furthermore, the NWMO's Environmental Protection Program, which includes an adaptive management component, will comply with CNSC licensing and federal/provincial permitting requirements. The NWMO will implement a Project-specific Environmental Monitoring Plan that includes monitoring of changes to fish habitat, as required, in accordance with conditions from the Regulatory Processes applicable to the Project. Follow-up and compliance monitoring programs will be developed and using adaptive management practices will be refined over time, informed by engagement with the Anishinaabe peoples of WLON and other potentially affected Indigenous Nations and communities.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RS0I-16	Birds (Including Migratory Birds) and Their Habitat	Birds and their habitat: Concerns regarding potential effects of the project on birds (migratory and non-migratory) and bird habitat, including resulting from changes to groundwater and surface water flows.	Project activities during all Project phases, including site clearing, blasting, construction of Project components, in-water works, altered site drainage, runoff, water withdrawal and discharge of treated effluent have the potential to directly and indirectly effect migratory and species at risk birds and their habitats (e.g., wetland and riparian disturbance, in-water construction, land clearing), including from changes to groundwater and surface water flows. See responses in this document to NWMO-RS0I-10 and NWMO-RS0I-15 for information as to how the NWMO will address potential changes to water quality and quantity, including changes to groundwater and surface water flows. Potential indirect adverse effects of the Project on migratory birds and bird species at risk from changes in groundwater and surface water flows will be managed through a combination of best management practices, environmental design features and mitigation measures, see the IPD Section 19 for a description of proposed mitigation measures. The effectiveness of these mitigation strategies is well-established and supported by industry experience and regulatory guidance. In addition to measures referred to in NWMO-RS0I-10 and NWMO-RS0I-15, key features and measures to avoid or minimize adverse indirect effects to migratory birds and bird species at risk from changes in groundwater and surface water flow include the following: • In-water infrastructure, such as freshwater intakes and effluent diffusers, will be designed to avoid injury or mortality to birds and reduce habitat disruption. • Runoff and seepage will be controlled using engineered drainage systems, containment structures, and water treatment processes so that surface water quality remains within known protective thresholds that meet regulatory standards for the receiving environment, including any requirements of Wabigoon Lake Ojibway Nation's (WLON) Regulatory Assessment and Approval Process (RAAP). Proposed measures in the Impact Statement will also consider those recommended by the Impact Assessment Agency of Canada (IAAC) in its List of Standard Mitigation Measures to mitigate potential effects to migratory birds (IAAC, 2026), including measures to mitigate: • Vegetation clearing, site preparation, blasting, and other land-disturbing activities • Lighting design and operation • Installation of transmission lines • Contact water management These practices are consistent with federal environmental protection regulations and best management practices to avoid or minimize potential changes in habitat availability and distribution due to changes groundwater and surface water flows that could result in a greater than negligible effect (i.e., a change similar to natural variation) on self-sustaining and ecologically effective migratory bird and species at risk bird populations. As presented in Section 19 of the IPD, environmental protection measures will be in place and effects on, hydrology and surface water quality will be mitigated to as low as reasonably achievable. Further assessment of potential effects on migratory birds and species at risk will be completed to meet licensing requirements under the <i>Nuclear Safety and Control Act</i> (NSCA), inform provincial and federal permitting requirements, and any requirements of WLON's RAAP. Through ongoing engagement, the Integrated Impact Statement will consider shared values and perspectives of the Anishinaabe peoples of WLON and other potentially affected Indigenous Nations and communities in the assessment of potential direct and indirect Project effects on migratory birds and bird species at risk, including the identification of proposed mitigation measures. Furthermore, the NWMO's Environmental Protection Program, which includes an adaptive management component, will comply with CNSC licensing and federal/provincial permitting requirements. The NWMO will implement a Project-specific Environmental Monitoring Plan that includes monitoring of changes to migratory bird and bird species at risk habitat, as required, in accordance with regulatory requirements). Monitoring programs will be developed and refined over time, informed by engagement with the Anishinaabe Nation of WLON and other potentially affected Indigenous Nations and communities.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-17	Human Health and Well-Being:	Cumulative effects on health in the region: Concerns regarding cumulative health effects in the region, particularly related to legacy industrial contamination, including the intergenerational health implications of historic mercury releases from Dryden Mill.	The Project will be considered in the historical context of past activities that have resulted in existing conditions, including legacy industrial contaminations, such as historic mercury releases from the Dryden Mill that have resulted in health impacts in the region. It is important to note that mercury is not used as part of the Project or Project activities. The NWMO is, however, aware that certain construction and land disturbance activities can influence biogeochemical conditions in the environment that may affect methylmercury production, including interactions with aquatic systems. These considerations are being examined through ongoing studies, and findings will be reported in the Integrated Impact Statement and Initial Licence Application, including through human health and ecological risk assessments (HHERAs). These studies form part of the Safety Case required under the <i>Nuclear Safety and Control Act</i> (NSCA). As part of this work, the NWMO is monitoring existing levels of mercury, methylmercury, and sulfate concentrations in soil, sediment, surface water, groundwater, and rock at the Project site, using appropriate and conservative analytical levels of detection. This information is being collected to inform optimization of Project design. The effectiveness of the Project's environmental design features, mitigation and protection measures is well established and broadly supported across industry and the NWMO anticipate that any potential residual effects on non-Indigenous health conditions will be mitigated. Under the NSCA, regulatory controls require the protection of human health by assessing and managing potential exposures to environmental contaminants. With these controls in place, any residual effects are expected to remain below applicable regulatory thresholds and to be sufficiently small that no measurable or noticeable impact on human health is anticipated. Given the robustness of the design and mitigation measures, it is unlikely that residual effects to health conditions materialize. Overall, residual effects to non-Indigenous health conditions from the Project are expected to be negligible in both magnitude and likelihood. This conclusion is reinforced through the NWMO's licensing obligations under the NSCA, which require comprehensive assessments, such as the HHERA, to identify, evaluate, and mitigate all potential exposure pathways and direct effects on human health. As such, consideration and additional evaluation of direct effects to non-Indigenous health conditions through the <i>Impact Assessment Act</i> is not anticipated, as direct health effects are already regulated through the NWMO's requirements under the <i>Nuclear Fuel Waste Act</i> (NFWA), see response NWMO-SOI-18 in this document for further information. The NWMO will continue to engage with the Anishinaabe peoples of WLON and other potentially affected Indigenous Nations and communities that may be affected by the Project to understand potential pathways of impact on their health and well-being. Future engagement will define valued components, measurement indicators and assessment endpoints to inform the scope of the assessment, receptor inputs to the HHERA, and the consideration of cumulative effects, if applicable. Further assessment will be undertaken through the integrated impact assessment process.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-18	Human Health and Well-Being:	Psychosocial health impacts: Concerns about the public perception and psychosocial impacts associated with living near the nuclear project, including impacts on mental health.	The robust, regular and systematic approach to socio-economic issues under the <i>Nuclear Fuel Waste Act</i> (NFWA) has sufficiently managed socio-economic issues for more than two decades. Conducting any additional assessment would be duplicative and may result in conflict with existing legal requirements. Moreover, the NFWA (which regulates the NWMO's use of funds in some respects) specifies a test for the NWMO's spending on socio-economic issues. If the integrated impact assessment process were to require mitigation on socio-economic issues in conflict with the NFWA (which has been passed by Canada's Parliament), it would create a conflict for the NWMO in complying with its legal obligations. If the Integrated Impact Assessment requires mitigation that can already occur, the impact assessment of socio-economic issues is not required. In short, the NWMO is already subject to an effective, legally binding, regulatory regime regarding the Project's socio-economic effects, that enables the NWMO to continue the implementation of agreements (many of which are and will be confidential) with communities to mitigate impacts the Project may have. As required by section 18 of the <i>Nuclear Fuel Waste Act</i> (NFWA), the NWMO is conducting and providing ongoing socio-economic assessment, analysis and reporting through its triennial reporting to Canada's Minister of Natural Resources. The report must include summaries of activities respecting the management of used nuclear fuel over the preceding three fiscal years and analyses of key social and economic effects of those activities on affected communities' way of life and their social, cultural, and economic aspirations. The NWMO has plans to develop a social, cultural, and economic reporting framework inclusive of social, cultural, and economic measures/topics and related qualitative and quantitative indicators to enable the continuous assessment of positive contributions or negative impacts on a community's way of life, priorities and aspirations over multiple years. Regular, systematic reporting on socio-economic information over time allows for analysis, oversight and proactive effects management related to changes in socio-economic circumstances under the NFWA. Moreover, regular, systematic reporting itself can be modified over time to adjust, if necessary, socio-economic trends related to the Project. The economic reporting framework will continue to build on community input over the years and will provide for active community involvement in monitoring of socio-economic effects management. It plays an important ongoing role in providing information to enhance Project implementation, and the effectiveness of the Project's implementation on mitigating such effects, which is further considered in the next triennial report. This framework, the reports, and the results are overseen by Canada's Minister of Natural Resources. In addition, the triennial reports are required to be laid before Canada's House of Commons and Senate, which enables review by Members of Parliament and Senators. The NWMO confirms that socio-economic mitigation measures for the Project have already been established and adopted pursuant to the NFWA, including through the implementation plan set out in Choosing a Way Forward. Chapter 14 of this report provides further information on Addressing Social, Economic and cultural Effects. The purpose of including these commitments in the integrated impact assessment process is to ensure clarity, transparency, and regulatory understanding of mitigation measures that are already planned for and being implemented.
NWMO-RSOI-19	Infrastructure and Services:	Effects of temporary workers on services and infrastructure: Concerns regarding the effects of an influx of temporary workers on local services and infrastructure, such as potential increases in the cost of living, and increased risks to vulnerable populations, including potential increases in gender-based violence. Concerns regarding the adequacy of mitigation measures for these effects.	A camp complex will be established on the Property. The worker accommodation camp will accommodate approximately 800 people during construction and then be decommissioned prior to operations. A portion of the workforce will come from outside the local community and work on a rotational basis and a camp is required to attract and retain people given the size of local communities. NWMO will also continue discussions with local municipalities to support considerations for potential housing improvement or infrastructure initiatives in the region. The NWMO is dedicated to actively engaging with diverse Indigenous Nations and communities, including women, men, gender diverse, youth, and Elders, to gather different viewpoints. Furthermore, the NWMO recognizes the ongoing risks faced by Indigenous women, girls, and 2SLGBTQIA people and supports The Final Report of The National Inquiry into Missing and Murdered Indigenous Women and Girls. The NWMO will work to address the Calls for Justice, with particular attention to number 13, which pertains to extractive and development industries. The NWMO commits to the ongoing implementation, monitoring, and reporting of socio-economic mitigation measures previously established under the <i>Nuclear Fuel Waste Act</i> (NFWA) and to transparently reporting on the effectiveness of those measures as the Project advances, as per the requirements of the NFWA (see response NWMO-SOI-18 in this document).

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-20	Infrastructure and Services:	Future service & infrastructure planning: Concerns regarding the difficulties of long-term planning for services and infrastructure given the multi-generational timeframe of the DGR.	Please see response to NWMO-RSOI-18 in this document.
NWMO-RSOI-21	Socio-Economic Conditions	Socio-economic effects of the project: Concerns regarding socio-economic effects to local communities and Indigenous communities for all phases of the project and the need for community-led baseline data collection.	Please see response to NWMO-RSOI-18 in this document. In addition, the NWMO will focus on providing Indigenous Nations and communities that may be affected by the Project appropriate opportunity to participate in the Project, through dialogue to share their insights, information sharing and Indigenous Knowledge.
NWMO-RSOI-22	Socio-Economic Conditions	Economic impact on property value: Concerns regarding the project's potential economic impacts on property and property value (e.g., land, homes, and businesses) of nearby residents, and how project activities may impact local properties and further affect property values.	Please see response to NWMO-RSOI-18 in this document.
NWMO-RSOI-23	Socio-Economic Conditions	Socio-economic impacts to land use: Need for information on how the project may affect the region's land use and access including recreation, tourism, fishing, hunting, forestry, plant harvesting, trapping, bear management area operations, bait harvesters and existing roads that are used by these land users.	Please see response to NWMO-RSOI-18 in this document.

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NWMO-RSOI-24	Socio-Economic Conditions	Distribution of economic benefits for all regional communities: Concerns that project- related economic benefits may not be equitably shared among all affected regional communities, including those outside hosting agreement areas.	Please see response to NWMO-RSOI-18 in this document.
NWMO-RSOI-25	Socio-Economic Conditions	Local economic "boom and bust" cycle: Concerns that the project may create a short-term increase in employment during early phases that is not sustained over the long term, and that local communities may experience disproportionate and limited economic benefits if a large portion of the workforce is temporary or resides outside the community.	The Project is unique given that site preparation, construction, operations and decommissioning and closure (including extended monitoring) will occur over a period of centuries, as opposed to years or decades that are more common to the forestry and mining sectors. In addition, extensive baseline data collection in the region indicates that historically and currently, many of the communities have been dependent on the natural resource economy (e.g., forestry, mining) and subject to the boom-bust cycles associated with those industries. Events such as the closure of forestry or mining operations resulted in decreases to the population as out-migration occurred when people sought economic opportunities elsewhere. These events have resulted in changes to the local population and are expected to persist without the Project, relative to the activities that continue to support the economy in the region. The NWMO has negotiated Hosting Agreements with both the Township of Ignace (Appendix C) and Wabigoon Lake Ojibway Nation that address the life cycle of the Project, including measures to mitigate against the implications of boom-bust cycles in the future. Additional socio-economic studies and transition planning will be completed, as required, under the <i>Nuclear Fuel Waste Act</i> as the Project moves through each phase to support the communities in these changes.
NWMO-RSOI-26	Socio-Economic Conditions	Economic impacts from public perception: Concerns that negative public perceptions associated with nuclear waste could impact local businesses, including their ability to attract customers and recruit or retain staff.	Please see response to NWMO-RSOI-18 in this document.
NWMO-RSOI-27	Socio-Economic Conditions	Long-term labour force, skills, and employment, and economic prosperity: Concerns regarding how the project may affect local employment, education, and training opportunities, including long-term job creation, sustainable economic benefits, skills development, business and procurement opportunities, and job security, as well as the need to understand the types, number, and duration of jobs across all project phases to assess economic impacts.	Extensive baseline studies indicate that labour demand in the region is expected to increase over the next three decades, and that meeting those demands will likely result in in-migration to the region as individuals and families seek to participate in the employment and business opportunities available. The Project will further contribute to these demands and could have effects on labour force characteristics, income, education, and training. Please see response to NWMO-RSOI-18 in this document. The NWMO confirms that socio-economic mitigation measures for the Project have already been established and adopted pursuant to the <i>Nuclear Fuel Waste Act</i>, including through the implementation plan set out in Choosing a Way Forward. Through the integrated impact assessment process, the NWMO is committed to meet and continue to implement these existing mitigation measures, and to transparently describe and report on them, rather than to establish duplicative impact assessment-specific socio-economic mitigation, follow-up, or monitoring programs. The purpose of including these commitments in the integrated impact assessment process is to ensure clarity, transparency, and regulatory understanding of mitigation measures that are planned and are already being implemented, including in a post-site-selection context. There are conditions within the Hosting Agreement with the Township of Ignace (Appendix C) to support sustainable economic benefits within the region. The integrated impact assessment process will consider potential impacts to economic conditions of Indigenous Nations and communities in the local and regional study areas.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-28	Socio-Economic Conditions	Social cohesion and community wellbeing: Concerns regarding potential impacts to community cohesion, wellbeing and lifestyle, food security, and safety due to influx of workers and division about the town hosting the project.	Please see response to NWMO-RSOI-18 in this document. The NWMO confirms that socio-economic mitigation measures for the Project have already been established and adopted pursuant to the <i>Nuclear Fuel Waste Act</i>, including through the implementation plan set out in Choosing a Way Forward. Through the integrated impact assessment process, the NWMO is committed to meet these commitments, continue to implement these existing mitigation measures, and to transparently describe and report on them, rather than to establish duplicative impact assessment-specific socio-economic mitigation, follow-up, or monitoring programs. The purpose of including these commitments in the integrated impact assessment process is to ensure clarity, transparency, and regulatory understanding of mitigation measures that are already planned for and being implemented, including in a post-site-selection context. There are conditions within the Hosting Agreement with the Township of Ignace (Appendix C) to support community health and well-being within the region. The assessment of the Project's potential changes to Indigenous health will include consideration of both biophysical determinants of health, along with the social determinants of health and well-being. Changes in social and economic conditions can result in changes to Indigenous community well-being and is expected to consider factors such as safety/security (individual and community), food security (including a diet and land use study), income inequality, and community cohesion. Gender-Based Analysis Plus (GBA Plus) will consider how different parts of Indigenous Nations and communities may experience these effects in unique ways.
NWMO-RSOI-29	Socio-Economic Conditions	Environmental justice: Concerns regarding disproportionate impacts to marginalized and/or racialized communities.	Please see response to NWMO-RSOI-18, in this document. The Integrated Impact Assessment will consider factors under federal jurisdiction listed in subsection 22(1) of the <i>Impact Assessment Act</i>, including the intersection of sex and gender with other identify factors. Gender-Based Analysis Plus (GBA Plus) will consider how different parts of Indigenous Nations and communities may experience these effects in unique ways.
NWMO-RSOI-30	Project description, purpose, need and alternatives considered	Future modifications for accepted waste in the DGR: Need more information on the type of waste that would be accepted in the DGR, the length of time it would remain radioactive and the potential for future project scope modifications that could change the types or volumes of waste managed in the DGR.	The purpose of the Project is to provide a permanent, safe, and environmentally responsible solution for the management of the used nuclear fuel. The DGR will safely contain and isolate the used fuel bundles in a stable geological formation, eliminating the need for ongoing active management and protecting people and the environment for generations to come. The Project will contain and isolate up to 5.9 million used fuel bundles, as outlined in NWMO's Nuclear Fuel Waste Projections - 2024 Update (NWMO, 2024). Low Level Waste (LLW) and Intermediate Level Waste (ILW) generated by the Project are also stored at the facility; LLW includes contaminated rags, mops, clothing and floor sweepings, and ILW includes certain wastes generated during the decontamination of certified transportation packages, Used Fuel Packaging Plant (UFPP) operational areas, and Used Fuel Container (UFCs). The LLW generated by the Project is planned for disposal within the DGR, while ILW is planned to be managed in a suitable facility, which will undergo a consent-based siting process. The volume of LLW and ILW waste generated during operations is estimated to be approximately 16,500 m³, housed within a packaging volume of approximately 36,300 m³. <u>Note that these are preliminary estimates of LLW and ILW generated during the operations. The estimates are subject to change as design and operation plans mature.</u> Any changes to the volume of used fuel or type of waste would require advance notification to and dialogue with the host communities. In addition, if any future modifications to the scope of the Project are ever to be proposed, it is anticipated that the NWMO will be required to submit a licence amendment application to the Canadian Nuclear Safety Commission (CNSC). The new licence would also require supporting information to demonstrate how the Project continues to meet applicable safety requirements and will not result in new or materially different environmental or human health effects beyond those assessed as part of the original Integrated Impact Statement. The radioactivity of used fuel decreases with time and drops significantly within the first thousand years. The remaining amount of radioactivity after one million years is similar to that in an equivalent amount of natural uranium ore. Decommissioning, final closure and the subsequent institutional control period and eventual release from licensing of the Project site will be governed by the CNSC following all associated requirements and will be informed by ongoing engagement with the public and potentially affected Indigenous Nations and communities.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-31	Project description, purpose, need and alternatives considered	Monitoring and institutional control: Concerns regarding monitoring methods, requirements, criteria for project modification, suspension and reversal and transparency in reporting monitoring results. Concerns regarding adequate consideration of intergenerational rolling stewardship, institutional control mechanisms and long-term access conditions.	As part of the Integrated Impact Statement, the NWMO will identify potential environmental, health, social, and economic effects of the Project, describe proposed mitigation measures, and outline follow-up and compliance monitoring programs to confirm the accuracy of the integrated impact assessment process and the effectiveness of mitigation measures. The Canadian Nuclear Safety Commission (CNSC), as the lifecycle regulator, will oversee the implementation of all approved mitigation, monitoring, commitment requirements and provide rigorous regulatory oversight across all phases of the Project. The Project is expected to have a lifecycle of approximately 160 years, including extended periods of monitoring during operations, closure, decommissioning and closure (including extended monitoring). The Project site will not be released from licence until the CNSC determines, through its regulatory oversight, that it is safe to do so. Long-term isolation and containment of the fuel in a deep geological repository is not reliant on institutional controls – but institutional controls do provide an additional level of confidence. Long-term monitoring and control of the site and facility is expected to continue for many decades, for as long as required by the CNSC and the licence conditions. At some point in the distant future, after confirming that the facility is performing as designed, and that there are no measurable effects to the environment, the CNSC may release the NWMO from its licensing regime and therefore its obligations. At that time, the enforcement of passive institutional controls may be transferred to the province or federal government. There is already precedent for this in Saskatchewan, where CNSC-licensed uranium mines are eventually transferred to a provincial institutional control program. Passive institutional controls are intended to persist for a long as possible. Under the NSCA, the NWMO will maintain a Public Information Program and Disclosure Protocol in accordance with CNSC REGDOC-3.2.1, <i>Public Information and Disclosure</i>, ensuring timely and accessible communication about Project safety and performance. The NWMO will also have to meet the reporting requirements outlined in REGDOC 3.1.2 <i>Reporting Requirements, Volume I: Non-Power Reactor Class I Facilities and Uranium Mines and Mills</i> which sets out requirements and guidance for reports and notifications that licensees must submit to the CNSC, including annual compliance monitoring reports. The NWMO recognizes the importance of intergenerational guardianship, institutional control mechanisms, and long-term access conditions, and acknowledges that approaches to these matters are necessarily conceptual at this stage of the Project. The NWMO is committed to ongoing engagement with Indigenous Nations and communities potentially affected by the Project and sees opportunities to understand how Indigenous intergenerational worldviews and principles may inform approaches to institutional control and custodianship. The NWMO will continue to engage with Wabigoon Lake Ojibway Nation and potentially affected Indigenous Nations and communities to consider their perspectives and rights as this work advances.
NWMO-RSOI-32	Project description, purpose, need and alternatives considered	Alternative means: Concern regarding the lack of options considered as alternative means for project activities and components, including alternatives related to the vertical shafts, used fuel processing plant, used fuel containers and storage of intermediate and low-level waste.	As stated in Section 12(a) of Schedule 1 (Information Required in the Initial Description of Designated Project) of the <i>Information and Management Time Limits Regulations</i> (SOR/2019-283), the IPD must include a list of potential alternative means of carrying out the project that the proponent is considering and that are technically and economically feasible, including through the use of best available technologies. The NWMO has been researching and analyzing means for implementing the Project for over 15 years. Throughout that time, decisions on the proposed Project, especially those around transportation, packaging and disposal of used nuclear fuel, have been made by prioritizing the protection and safety of people and the environment. The requirement under the <i>Impact Assessment Act</i> (IAA) for assessing alternative means is to focus on realistic, implementable options that are technically feasible and economically viable. During the Impact Statement phase, the assessment of alternative means will apply qualitative and quantitative criteria to evaluate each option for each of the identified Project components / activities requiring further assessment. These criteria will consider potential effects on the environment and people, as well as the technical and economic feasibility of each option, to identify the preferred option for each Project component or activity being assessed. In developing the IPD, the NWMO reviewed all Project components and activities to determine where multiple technically and economically feasible options exist and where those options can be meaningfully evaluated against environmental and social criterion. The list of alternative means presented in the IPD reflects this evaluation. The current list includes components and activities related to conventional, industrial, and radiological waste management, water management, worker accommodation, and new access and utility corridors to the site. These Project components and activities align with the concerns raised during the public review of the IPD and warrant further assessment and engagement. Through the Integrated Impact Statement phase, the NWMO will continue to engage with the Anishinaabe peoples of Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities to further define the list of options for each of the proposed alternative means to be assessed in the assessment of alternative means. Through this engagement, the NWMO will also seek perspectives on Indigenous and social criteria, ensuring that public and Indigenous input informs the assessment of alternative means.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-33	Accidents and Malfunctions	High uncertainty novel project potential for accidents and malfunctions: Concerns regarding the novel project design, the high uncertainty, unanticipated problems, and limited international case studies to confirm long-term facility performance to avoid potential effects or accidents and malfunctions.	While the Project may seem as though it is a first-of-its-kind project for the long-term management of used nuclear fuel in Canada, it is informed by Canadian and international precedent and subject to rigorous regulatory oversight. Canada has previously undertaken federal environmental assessments of deep geological repository concepts, including the Seaborn Panel review of Atomic Energy of Canada Limited's disposal concept and the environmental assessment of Ontario Power Generation's proposed deep geological repository under the <i>Canadian Environmental Assessment Act, 2012</i>. These reviews concluded that the DGR concept is technically sound and safe, while also reinforcing the importance of Indigenous partnership, informed willingness, and public confidence. There is high certainty respecting the Project and the design based on known precedents. The Project involves a combination of conventional nuclear fuel handling steps. In the long-term, the Project relies on a set of engineered and natural barriers. The performance of these barriers is based on scientific evidence, including the behavior of natural analogs for these materials that demonstrate their capability for durability. In particular, the host rock is 2.7 billion years old and has demonstrated capacity to endure through large natural events. And as time passes, the inherent natural radioactive decay of the used fuel will reduce its potential hazard. Our present confidence in these features has been summarized in the Confidence in Safety - Revell Site - 2023 Update report. Further details on the assessment of malfunctions and accidents will be provided in the Integrated Impact Statement. As part of the Integrated Impact Statement, the NWMO will identify potential effects of the Project, describe proposed mitigation measures, and outline follow-up and monitoring programs to confirm the accuracy of the integrated impact assessment process and the effectiveness of mitigation measures. The Canadian Nuclear Safety Commission (CNSC), as the lifecycle regulator, will oversee the implementation of all approved mitigation, monitoring, and commitment requirements and provide rigorous regulatory oversight across all phases of the Project. The assessment will also consider climate change and resilience as part of the federal Strategic Assessment of Climate Change (SACC). The Project is expected to span approximately 160 years, including an extended period of monitoring before decommissioning and closure. The Project will only advance through a series of licensing steps, which will provide control and decision on when and how to proceed to the next step. These licensing step decisions will be made in consultation with the communities, and under regulatory oversight and approval. The NWMO continues to work with other national waste management organizations that are implementing similar projects, to ensure that information is shared. Partnering with other radioactive waste management organizations allows us to foster international co-operation on the development and demonstration of technology, learn from other countries' experience, and keep abreast of developments in repository design and safety case development for similar host rock formations.
NWMO-RSOI-34	Accidents and Malfunctions	Failure of any critical DGR component: Concerns regarding potential accident and malfunction scenarios that could lead to DGR failure and radiological release into the environment, and the need for information on whether the used fuel containers could be retrieved under such circumstances.	The Project provides a safe, permanent, and responsible solution that will ensure the used fuel is securely contained and isolated from people and the environment for generations to come. The repository uses multiple barriers that include the waste form, container, sealing materials and host rock, and the system is designed such that the failure of one component will not jeopardize the safety of the containment system as a whole. An assessment of accidents and malfunctions is undertaken in support of the Integrated Impact Statement for the Project. The assessment considers a range of potential accident scenarios, including credible abnormal events and accidents with a very low likelihood of occurring, and estimates the likelihood and consequences of potential radiological releases to people and the environment during the Project phases. In the event of an accident before repository closure, mitigation measures and emergency response plans will limit the consequences and keep people and environment safe. The underground placement rooms are intended for permanent disposal of the used fuel containers, but the containers could be retrieved using remote equipment. During the extended monitoring period after placement, the repository remains in service; this period provides opportunity to confirm the containers are behaving as expected, or to consider further mitigating measures if needed. A conceptual Post-Closure Safety Assessment, developed in support of the Initial Licence Application, considers scenarios where used fuel containers could fail after repository closure. Even in these cases, the estimated impacts from the repository on people and the environment are expected to be well below the natural background and the regulatory dose limits. The assessment is consistent with the Canadian Nuclear Safety Commission (CNSC) graded approach, which allows for detailed design information to be developed and refined at later licensing stages.

Response Identifier	Comment Topic	Summary of Issue	NWMO Response
NWMO-RSOI-35	Accidents and Malfunctions	Used Fuel Packaging Plant: Concerns about potential accidents in the Used Fuel Packaging Plant (UFPP), their potential effects, and associated mitigation measures to address them.	The Used Fuel Packaging Plant (UFPP) is a robust facility, designed to isolate and contain the used fuel during packaging operations. The handling operations that involve used fuel will be completed within heavily shielded enclosures (i.e., hot cells). Fuel handling will use remote tooling and shielded transfer packages. All shielded cells will be environmentally controlled by a filtered ventilation system to prevent the spread of airborne radioactivity. Potential accidents in the UFPP are identified and assessed through a systematic approach. A Pre-closure Safety Analysis is developed consistent with Canadian Nuclear Safety Commission (CNSC) REGDOC-2.4.4, <i>Safety Analysis for Class IB Nuclear Facilities</i>. The analysis considers a range of potential hazards, including equipment failure within the UFPP, worker error, or external hazards, such as earthquakes, flooding, tornados, and extreme meteorological phenomena. These hazards are screened to identify potential interactions between the hazard and the Project facility that could affect the safe operation of the facility. For events that could credibly result in a release of radioactivity, the potential impact on people and the environment is assessed to demonstrate that even in the unlikely event of accidents, the facility will be safe. Mitigation measures and emergency response plans will limit the consequences and keep the people and environment safe in case of potential accidents. An environmental monitoring program will be implemented throughout the lifespan of the Project and will include monitoring activities to verify that risks remain well below levels that could pose harm to people or the environment. Monitoring and mitigation measures will be refined as the integrated impact assessment process advances and may also evolve based on engagement outcomes and findings from ongoing analyses.
NWMO-RSOI-36	Accidents and Malfunctions	Emergency preparedness: Concerns regarding the ability of local services and infrastructure to respond to potential emergencies, and the need for adequate development, funding, and communication of emergency response plans, procedures, and program exercises in rural settings to potentially impacted communities.	Through engagement undertaken during site selection and as part of engagement on the IPD with host communities, the NWMO understands that Indigenous Nations and communities, the public, and Canadians have a strong interest in continued dialogue on design rationale, risk mitigation, and emergency preparedness, including how emergency response planning will extend across neighbouring communities and how local emergency personnel will be trained, resourced, and coordinated to respond to potential events. As documented in the Licensing Appendix to the IPD (beginning on PDF page 317), emergency preparedness is a foundational component of the licensing process and is subject to the CNSC emergency management framework. If the NWMO is successful in obtaining Impact Assessment and Initial Licensing Approvals, the Impact Assessment Decision Statement and the licence issued by the Canadian Nuclear Safety Commission (CNSC) will include enforceable requirements for the protection of people and the environment, such as requirements for emergency preparedness and response plans, limits on radioactive and hazardous releases, and obligations for environmental monitoring and emissions reporting. Consistent with CNSC REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>, the licence application must describe an emergency preparedness program that meets the requirements of REGDOC-2.10.1 <i>Nuclear Emergency Preparedness and Response</i>, including emergency management and fire protection measures. In addition, the NWMO will be required to develop a public information and disclosure program, in accordance with CNSC's REGDOC 3.2.1, <i>Public Information and Disclosure</i> to ensure that information related to the health, safety and security of persons and the environment, and other issues associated with the lifecycle of the Project, such as emergency response plans, are effectively communicated to the public. The NWMO remains committed to sharing information on emergency preparedness planning and ensuring that emergency response arrangements are informed by engagement as the regulatory review proceeds.

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NWMO-RSOI-37	Accidents and Malfunctions	Security Risks and Safeguards: Concerns that the project could increase risks of nuclear proliferation and targeted malevolent acts (e.g., terrorist activity) throughout the entire project lifecycle, including security risks during transportation of used nuclear fuel and potential future retrieval from the DGR after institutional control is released from the NWMO.	The NWMO recognizes the applicability of Canadian Nuclear Safety Commission (CNSC) REGDOC-2.13.1 <i>Safeguards and Nuclear Material Accountancy</i>, with respect to safeguard requirements for the Project. While there are no safeguards requirements in the pre-licensing phase of the Project, REGDOC-1.2.3 does require that the NWMO provide a description of the arrangements, as applicable to site preparation, that will permit the CNSC to discharge Canada's obligations and provide information to the International Atomic Energy Agency. The NWMO is also required to describe its plan to document measures related to a safeguards program for the full lifecycle of the Project. These plans are under development and are to be submitted to the CNSC as part of the Initial Licence Application. The NWMO intends to engage with the CNSC and International Atomic Energy Agency on potential safeguards measures for the future facility early in the design process. After closure of the repository, all shafts are completely backfilled and sealed, preventing any further access. Long-term isolation and containment of the fuel in a deep geological repository is not reliant on institutional controls – but institutional controls do provide an additional level of confidence. Long-term monitoring and control of the site and facility is expected to continue for many decades, for as long as required by the CNSC and the licence conditions. At some point in the distant future, after confirming that the facility is performing as designed, and that there are no measurable effects to the environment, the CNSC may release the NWMO from its licensing regime and therefore its obligations. At that time, the enforcement of passive institutional controls may be transferred to the province or federal government. There is already precedent for this in Saskatchewan, where CNSC-licensed uranium mines are eventually transferred to a provincial institutional control program. Passive institutional controls are intended to persist for a long as possible. While retrieval of fuel from the repository post-closure is technically feasible, it is a slow, hazardous, and expensive task, one that would require enormous planning, time, and resources, and at this time would only be considered in exceptional circumstances. The difficulty and cost of retrieving waste is itself a deterrent to intentional human intrusion into the facility, and one of the many reasons why a deep geological repository is well suited for the long-term containment and isolation of used fuel. The NWMO used fuel transport operations will not commence until at least 2043. Before any shipments of used nuclear fuel can begin, the NWMO will be required to demonstrate to regulatory authorities that all applicable safety and security requirements have been met. This includes the development, submission, and approval of a comprehensive Security Plan. Current regulations do not allow the public disclosure of security information on the location, routes and timing of shipments, nor any security arrangements or procedures specific to the transportation of used nuclear fuel. This type of information is considered prescribed and is limited to persons who have a legitimate need to know, such as police response forces.
NWMO-RSOI-38	Transportation	Accidents during transportation of waste: Concerns related to accidents and effects to the Indigenous and local communities and the environment along the general transportation corridor and public communication mechanisms including emergency preparedness.	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. This concern relates to transportation activities outside of the Project site and therefore outside of the Project scope. The response is being provided for informational purposes and to address related concerns. The NWMO used fuel transport operations will not commence until at least 2043. Before any shipments of used nuclear fuel can begin, the NWMO will be required to demonstrate to regulatory authorities that all applicable safety and security requirements have been met, as part of the approval and ongoing oversight by the lifecycle regulator. This includes the development, submission, and approval of a comprehensive Emergency Response Plan and a Security Plan. In over 60 years of transportation shipments of radioactive materials worldwide, while there have been accidents involving packages containing radioactive material, no harm to humans or the environment has resulted from radioactive release from any transportation accident. This is because safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging for used fuel provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Used fuel is a solid material that cannot spill. It will be transported in a certified package that is designed and tested to protect the public and the environment under both normal operating conditions and severe accident conditions. The test conditions described in the safety standards are used to demonstrate that a package can provide adequate radiation shielding and containment of radioactive materials under normal conditions of

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			transport and the conditions expected in a severe accident. The packages must be designed to withstand a drop test, puncture test, fire test and immersion test to simulate cumulative accident scenarios, including immersion in water. Additionally, in response to questions and comments received during extensive engagement on the NWMO's broader transportation program, which is outside of the scope of this project, the NWMO reviewed and analyzed real-world accident reconstructions to predict the performance of used fuel packages and transport systems under severe real-world accident conditions. In all scenarios, had these accidents involved used fuel transportation packages, the packages would have survived the accidents and met regulatory requirements for containment and dose rate limits, demonstrating the robustness of the regulatory framework. For more information about transportation packages used to transport used nuclear fuel, please see our Confidence in Transportation Package Performance report (Appendix D). Two other publicly available reports that address concerns related to potential accidents include: • Transportation Collision Data Analysis Report (Appendix E) • Transportation Collision Mitigation Report (Appendix F) The purpose of Appendix F was to gather, analyze, and assess available collision data relevant to the modes (road and rail) and types of conveyances proposed to transport used fuel to the Project site. This study analyzed and assessed collision data to understand the types of collisions, severity, and potential causal factors (including inclement weather). This was then used to develop the mitigation report - to look at collision probabilities, patterns, and trends identified in this report which <u>specifically</u> explored potential preventative and mitigating measures that can be leveraged by the NWMO to reduce the likelihood of transportation collisions. In Canada, the emergency management community has adopted a standard approach for responding to incidents. Federal, provincial, and local governments use a comprehensive approach to emergency management, which includes having in place measures for prevention, mitigation, preparedness, and response and restoration activities for all modes of transportation. The NWMO will provide a transportation emergency response plan to the Canadian regulatory agencies to demonstrate that appropriate emergency measures are in place. The purpose of the emergency response plan is to ensure co-ordination among the NWMO, provincial, and local first responders, as well as federal agencies. It should be noted that first responders have general training on response protocol for dangerous goods, and any supplemental training or awareness programs will build on this knowledge base. Additionally, specialized teams with expertise and training in response and recovery will be dispatched by the NWMO in the event of an accident involving a transportation package. The NWMO published a Preliminary Transportation Plan (Appendix G) in 2021, which describes a conceptual approach to transportation safety during the early design phase. This plan outlines potential safety and operational features that may be considered as the transportation system is further developed, including enhanced vehicle safety technologies, shipment monitoring and communications through a transportation command centre, escort vehicles to identify potential hazards, and operational controls that account for weather, road conditions, and other factors. As described in the plan, shipments will be managed conservatively, with the ability to delay or adjust transport under adverse conditions. These concepts are intended to inform ongoing planning and engagement and may evolve as design, regulatory review, and licensing progress. In addition, the NWMO will be required to develop a public information and disclosure program, in accordance with Canadian Nuclear Safety Commission (CNSC) REGDOC 3.2.1, <i>Public Information and Disclosure</i>. Depending on the type of facilities/activities and interests of the target audience, the information to be disclosed may include serious vehicle or industrial accidents, routine and non-routine releases of radiological and hazardous materials to the environment, and unplanned events, including those exceeding regulatory limits. Based on NWMO's studies, and the stringent regulatory framework, the NWMO has determined that, although accidents may occur despite the mitigation measures and strong regulatory oversight, the consequence of an accident would be low due to the nature of the transportation package.

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NWMO-RSOI-39	Transportation	Transportation in scope of impact assessment: Concerns related to exclusion of transportation from the scope of this project and impact assessment.	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. Transportation beyond the Project site is not part of the Project scope. As part of the integrated impact assessment process for the Project, NWMO is assessing the potential effects of all transportation activities at the Project site, including transportation along the primary and secondary access roads within the site. This includes the movement of used nuclear fuel and other Project-related materials once they arrive at, and are handled within, the Project site. Loading of the used fuel into the certified transportation packages at the facilities where it is currently stored is an activity that is assessed and included as part of those facilities' licences. This site-specific assessment focuses on how transportation activities associated with the Project may interact with the environment, communities including Indigenous Nations and communities, and land uses at the Project site. The NWMO used fuel transport operations will not commence until at least 2043. As outlined in the IPD, the transportation of used fuel from reactor sites to the Project site, beyond the primary and secondary access roads at the site, will be addressed through a separate federal regulatory framework. That transportation is regulated through the Canadian Nuclear Safety Commission (CNSC) transportation certification and licensing process and Transport Canada's <i>Transportation of Dangerous Goods Regulations</i> and relies on existing transportation infrastructure. Please refer to responses to NWMO-RSOI-38 and NWMO-RSOI-40 in this document and to the CNSC's website for more information on the regulatory framework for the transportation of radioactive materials. The philosophy behind the transportation of radioactive materials, including used fuel, is that safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging itself provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Please refer to the Preliminary Transportation Plan (Appendix G) for more information. Before any shipments of used nuclear fuel can begin, the NWMO will be required to demonstrate to regulatory authorities that all applicable safety and security requirements have been met. This includes the development, submission, and approval of a comprehensive Emergency Response Plan and a Security Plan. Current regulations do not allow the public disclosure of security information on the location, routes and timing of shipments, nor any security arrangements or procedures specific to the transportation of used nuclear fuel. This type of information is considered prescribed and is limited to persons who have a legitimate need to know, such as emergency response forces. To date we have engaged with thousands of Canadians and Indigenous Nations and communities to understand their perspectives, suggestions, questions and concerns about the transportation of used nuclear fuel. The NWMO's Transportation Planning Framework (Appendix H) describes the questions and concerns the NWMO have heard from this engagement and commits the NWMO to broadly engaging on transportation over the planning process (between now and 2043, when operations are estimated to begin). The NWMO will continue to engage with Indigenous Nations and communities and organizations that express an interest. The Framework will be updated later this year. Together, these processes ensure that transportation is comprehensively regulated, with the Impact Assessment addressing potential Project-site effects and the CNSC certification process addressing the safety and regulation of used fuel transportation along the broader transportation corridor.

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NWMO-RSOI-40	Transportation	Transportation damage to transport package: Concerns regarding the transportation package integrity include the potential for damage during transport, the degradation of package performance and integrity over prolonged use, and the need for proper end-of-life disposal to ensure continued safety.	The transportation of used nuclear fuel is a well-established and highly regulated activity in Canada and internationally. Used fuel is a solid material that cannot spill. Additionally, it will be transported in a certified package that is designed and tested to protect the public and the environment under both normal operating conditions and severe accident conditions. The test conditions described in the safety standards are used to demonstrate that a package can provide adequate radiation shielding and containment of radioactive materials under normal conditions of transport and the conditions expected in a severe accident. The packages must be designed to withstand a drop test, puncture test, fire test and immersion test to simulate cumulative accident scenarios, including immersion in water. An important tool in addressing the safety of used fuel shipments is the use of accident reconstructions to predict the performance of used fuel packages and transport systems under severe real-world accident conditions. The NWMO reviewed and analyzed real-world accident reconstructions. In all scenarios, had these accidents involved used fuel transportation packages, the packages would have survived the accidents and met regulatory requirements for containment and dose rate limits, demonstrating the robustness of the regulatory framework. For more information about transportation packages used to transport used nuclear fuel, please see our Confidence in Package Performance report (Appendix D). As required by the Canadian Nuclear Safety Commission (CNSC) <i>Packaging and Transportation of Nuclear Substances Regulations</i>, the NWMO will be required to develop a maintenance program used to ensure continued performance of the packaging. This program will include, as applicable, periodic testing, inspection, and replacement schedules, as well as criteria for replacement and repair of components and subsystems on an as-needed basis. With respect to end-of-life of the packaging, the CNSC requires the NWMO to develop a comprehensive waste management program to address all waste generated throughout its lifecycle, including transport packaging that has reached its end-of-life.
NWMO-RSOI-41	Transportation	Radiological effects from transportation: Concerns regarding the environment and the health of Indigenous and local communities along the transportation route and workers that may be exposed to radiation.	Packages designed to transport used nuclear fuel must meet radiation level requirements prescribed by the Canadian Nuclear Safety Commission (CNSC) <i>Packaging and Transport of Nuclear Substances Regulations</i>, 2015. Regulatory requirements for the package ensure a high level of safety of the public, workers, and the environment. The package is designed to prevent releases and tested to ensure that in the event of an accident, any radiological release will not exceed the regulatory limits. The CNSC's Radiation Protection Regulations have set an annual radiation dose limit for members of the public to limit exposure from nuclear-related activities, using the ALARA principle (as low as reasonably achievable). In 2012, the NWMO prepared an assessment that estimated radiological dose to members of the public resulting from the transport of used nuclear fuel in the Used Fuel Transportation Package (UFTP). The dose estimates were built around generic, internationally available exposure time, distance and frequency assumptions. In 2014, work was initiated to refine these assumptions and to frame them in a Canadian context. Carleton University was contracted by the NWMO to assess exposure times, distances and frequencies between the members of the public and a passing UFTP along a hypothetical transport route. The data collected by Carleton reflects a realistic, current Canadian perspective on the time, distance and frequency relationships between members of the public and a UFTP shipment. Radiological doses to members of the public were estimated to range between approximately 0.0000013 to 0.00054 mSv per year with certain roadway workers potentially receiving the highest dose. All doses were calculated to be orders of magnitude below the regulatory dose limit of 1 mSv per year for a member of the public. The member of the public receiving the highest annual dose was determined to be a traffic control person (roadside worker), who may receive an annual dose 1900 times less than the public dose limit or a dose equivalent to that received during 8 minutes of flight in a jet airplane. For workers, occupational doses were assessed to be within a range of approximately 0.012 to 0.35 mSv per year with members of the transport crew receiving the highest dose; approximately 1/3rd of the public dose limit, or equivalent to the dose received during 88½ hours of flight in a jet airplane. The transport crew will receive only about 15% of the dose a typical flight crew receives annually. For more information on doses from transportation of used fuel, please refer to the NWMO report: Assessing Radiological Dose to Members of the Public and Workers during UFTP Transportation (NWMO, 2015). Additionally, please refer to the Worker Dose Assessment (Appendix I) and the Public Dose Assessment (Appendix J).

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NWMO-RSOI-42	Transportation	Transportation method: Concerns regarding the preferred method, including fuel packaging methods for transporting used nuclear fuel to the project site, including the uncertainty about whether transport would occur by road, rail, or a combination of both.	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. This concern relates to transportation activities outside of the Project site and therefore outside of the Project scope. The response is being provided for informational purposes and to address related concerns. The philosophy behind the transportation of radioactive materials, including used fuel, is that safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging itself provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Please refer to the responses to NWMO-RSOI-38 and NWMO-RSOI-40 in this document and to the Preliminary Transportation Plan (Appendix G) for more information. Loading of the used fuel into the certified transportation packages at the facilities where it is currently stored is an activity that is assessed and included as part of those facilities' licences. The NWMO is looking at two options, either: 1) An all-road used fuel transportation system; or 2) A road/rail used fuel transportation system. For planning purposes, the all-road used fuel transportation system is referred to as the NWMO's reference case. This is the option that is considered for lifecycle cost estimates to ensure accountability and transparency as the NWMO implement Canada's plan. The road/rail used fuel transportation system is referred to as the alternative case. Both transportation mode options can be safely implemented to the potential Project location. The designs for these two systems have been established and consider the following: regulatory requirements; the use of various transportation packages; potential vehicles (e.g., trucks/ rail cars); associated fleet requirements for transport packages; representative routes; nuclear security and escort arrangements; emergency management, including response and recovery; logistics and scheduling of shipments; as well as operational aspects such as communication, monitoring and tracking of shipments. Please refer to the Preliminary Transportation Plan (Appendix G) for more information.
NWMO-RSOI-43	Transportation	Wildlife-vehicle collisions: Concerns regarding project-related transportation activities increasing the potential for wildlife–vehicle collisions over the operational lifespan.	As part of the integrated impact assessment process, the NWMO is assessing the potential effects of all transportation activities at the Project site, including transportation along the primary and secondary access roads within the site. Vehicles at the Project site and access roads could increase the potential of collisions with terrestrial wildlife resulting in injury or death of individual wildlife. During operations, the NWMO anticipates two to three used fuel shipments arriving at the Project location per day, six days per week, nine months per year. This represents about a 0.5% increase in existing traffic volumes on the TransCanada Highway and is therefore not expected to have a substantive increase in potential wildlife–vehicle collisions. Transport Canada's <i>Transportation of Dangerous Goods Regulations</i> establish requirements for worker and driver training, emergency planning, safety marks (e.g., placards) and documentation. In addition, emergency response planning will be required through the Canadian Nuclear Safety Commission (CNSC) licence conditions. Transportation planning will address these aspects so that all equipment, packages and activities for road and rail shipments meet regulatory requirements. The NWMO will be required to demonstrate that all activities will be conducted by trained personnel, including emergency responders. The NWMO will also be required to develop an emergency response plan and train workers and emergency responders before shipments can begin. As described in Table 19.4 and Appendix E of the IPD, preliminary proposed mitigation measures to avoid or minimize potential wildlife collisions include speed limits and reporting procedures for wildlife collisions or observances along the access road and rail spur. Given the proposed mitigation and environmental protection measures required and regulatory controls in place, the NWMO anticipates limited residual effects on terrestrial wildlife and wildlife habitat. Further assessment of potential effects on terrestrial wildlife and wildlife habitat, including potential effects from vehicle collisions, will be completed to meet licensing requirements under the <i>Nuclear Safety and Control Act</i> (NSCA) and will be informed by provincial and federal permitting requirements. The NWMO will continue to engage with Wabigoon Lake Ojibway Nation and potentially affected Indigenous Nations and communities regarding proposed mitigation measures to avoid and minimize potential effects of the Project.

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NWMO-RSOI-44	Transportation	Transportation service and infrastructure preparedness and demand: Concerns relating to emergency preparedness of communities along the transportation route, and the capacity, existing by-laws/regulation and demands on existing infrastructure (e.g., roads and bridges) and emergency services (e.g., hospitals, fire, police, and first responders), given concerns related to increased local transportation and transportation-related accidents.	Transport Canada's <i>Transportation of Dangerous Goods Regulations</i> establish requirements for worker and driver training, emergency planning, safety marks (e.g., placards), and documentation. In addition, emergency response planning will be required through the Canadian Nuclear Safety Commission (CNSC) licence conditions. Transportation planning will address these aspects so that all equipment, packages and activities for road and rail shipments meet regulatory requirements. The NWMO will be required to demonstrate that all activities will be conducted by trained personnel, including emergency responders. The NWMO will also be required to develop an emergency response plan and train workers and emergency responders before shipments can begin. The emergency response plan may include, but is not limited, to the following: • Description of the emergency response organization and external agencies, as well as their roles, responsibilities, capabilities, and duties, and how they will work together • Agreements on assistance with other facilities and/or other organizations • Plans for mobilizing and deploying resources for response • Description of roles and responsibilities (e.g., driver, escort, the NWMO transportation command centre staff, first on the scene team, response team, recovery team) • Training and qualification requirements, as well as drills and joint exercises; and • Communication protocols, as well as procedures for alerting and notifying key organizations and personnel, as well as the public Please refer to the Preliminary Transportation Plan (Appendix G) for more information. With respect to demands on existing infrastructure, a truck carrying used fuel is roughly the same size and weight as a logging truck, well within the existing design capacity of the highway. During operations, the NWMO anticipates two to three used fuel shipments arriving at the Project location per day, six days per week, nine months per year. This represents about a 0.5% increase in existing traffic volumes on the TransCanada Highway.
NWMO-RSOI-45	Transportation	Socio-economic impacts of transport accidents: Concerns regarding economic impacts resulting from accident-induced disruptions to the transportation corridors for communities along the transportation route.	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. This concern relates to transportation activities outside of the Project site and therefore outside of the Project scope. The response is being provided for informational purposes and to address related concerns. In over 60 years of transportation shipments of radioactive materials worldwide, while there have been accidents involving packages containing radioactive material, no harm to humans or the environment has resulted from radioactive release from any transportation accident. This is because safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging for used fuel provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Please refer to NWMO-RSOI-38 and NWMO-RSOI-40 for more information on the packaging. Used fuel is a solid material that cannot spill. Additionally, it will be transported in a certified package that is designed and tested to protect the public and the environment under both normal operating conditions and severe accident conditions. The packages must be designed to withstand a drop test, puncture test, fire test, and immersion test. Additionally, in response to questions and comments received during extensive engagement on transportation, the NWMO reviewed and analyzed real-world accident reconstructions to predict the performance of used fuel packages and transport systems under severe real-world accident conditions. In all scenarios, had these accidents involved used fuel transportation packages, the packages will have survived the accidents and met regulatory requirements for containment and dose rate limits, demonstrating the robustness of the regulatory framework. For more information about transportation packages used to transport used nuclear fuel, please see the NWMO's Confidence in Package Performance report (Appendix D). Transport Canada's <i>Transportation of Dangerous Goods Regulations</i> establish requirements for worker and driver training, emergency planning, safety marks (e.g., placards), and documentation. Emergency response planning will be required through the CNSC licence conditions as well. Transportation planning will be required to address these aspects and ensure that all equipment, packages and activities for road and rail shipments meet regulatory requirements. The NWMO will also be required to demonstrate that all activities will be conducted by trained personnel,

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			including emergency responders. The NWMO will also be required to develop an emergency response plan and ensure workers and emergency responders are trained before shipments can begin. The emergency response plan may include, but is not limited to the following: • Description of the emergency response organization and external agencies, as well as their roles, responsibilities, capabilities, and duties, and how they will work together • Agreements on assistance with other facilities and/or other organizations • Plans for mobilizing and deploying resources for response • Description of roles and responsibilities (e.g., driver, escort, NWMO transportation command centre staff, first on the scene team, response team, recovery team, etc.) • Training and qualification requirements, as well as drills and joint exercises; and Communication protocols, as well as procedures for alerting and notifying key organizations and personnel, as well as the public Please refer to the Preliminary Transportation Plan (Appendix G) for more information. In addition, the NWMO will be required to develop a public information and disclosure program, in accordance with Canadian Nuclear Safety Commission (CNSC) REGDOC 3.2.1. Depending on the type of facilities/activities and interests of the target audience, the information to be disclosed may include serious vehicle or industrial accidents, routine and non-routine releases of radiological and hazardous materials to the environment, and unplanned events, including those exceeding regulatory limits. In the history of transporting used nuclear fuel globally (60 years), there has never been an accident resulting in human and environmental harm as a result of radioactive release. Given the low consequence of a transportation accident involving used nuclear fuel (refer to the NWMO-RSOI-38 answer in this document), the economic impacts resulting from accident-induced disruptions would be similar to that of a conventional transportation accident. In any accident scenario, be it used fuel or conventional, the focus would be to restore the accident site to normal operations as soon as is safe to do so.
NWMO-RSOI-46	Transportation	Transportation and engagement: Concerns regarding the lack of meaningful engagement or consultation, and consent from Indigenous and local communities along the transportation corridor, including how their knowledge and expertise is considered.	To date the NWMO has engaged with thousands of Canadians and Indigenous Nations and communities to understand their perspectives, suggestions, questions and concerns about the transportation of used nuclear fuel. The NWMO's Transportation Planning Framework (Appendix H) describes the questions and concerns we have heard from this engagement and commits the NWMO to broadly engaging on transportation over the planning process (between now and 2043, when operations are estimated to begin). The NWMO will continue to engage with Indigenous Nations and communities and organizations that express an interest. The Framework will be updated later this year.
NWMO-RSOI-47	Transportation	Cumulative Transportation Effects: Concerns regarding potential cumulative effects along the transportation corridor.	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. Please see the response to NWMO-RSOI-39 in this document, regarding concerns related to the transportation scope of the Project for impact assessment. Transportation of used nuclear fuel to the Project site will rely on existing vehicular infrastructure and is subject to a separate federal regulatory framework administered by the Canadian Nuclear Safety Commission (CNSC) and Transport Canada. Concurrent with regulatory engagement to support the regulatory processes, the NWMO intends to continue broader communications and engagement with communities to support ongoing dialogue, information sharing, and relationship-building related to its broader work, recognizing that these conversations serve different purposes but remain important to communities.

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NWMO-RSOI-48	Transportation	Climate change effects on transportation: Concerns that climate change may increase the frequency or severity of accidents due to deteriorating road conditions, or require detours to avoid extreme events (e.g., flooding or wildfires).	Shipments will be dependent on the conditions such as weather, road restrictions and unscheduled maintenance. In this conceptual design phase, we are conservatively assuming that for about 30 to 90 days of the year, we may not be able to transport used fuel due to these conditions. The NWMO has undertaken several recent studies to analyze collision data and understand potential mitigation measures. More information can be found in the following reports: - Transportation Collision Data Analysis Report (Appendix E) - Transportation Collision Mitigation Report (Appendix F) The NWMO will take actions to prevent accidents and manage risks, including route selection, communications, and real-time monitoring and tracking. Most importantly, if an event is detected along the transportation route in advance of a transportation shipment, such as bad weather or a highway closure, the shipment will not go out, or an alternate route will be used (depending on the situation). Please refer to the Preliminary Transportation Plan (Appendix G) for more information.
NWMO-RSOI-49	Transportation	Length of transportation corridor: Concerns regarding the potential length of the transportation route for used nuclear fuel and associated number of communities	The assessment of transportation within the scope of the Integrated Impact Assessment should be limited to the area where the NWMO will be making physical changes as part of this Project. As part of the integrated impact assessment process, the NWMO will assess the potential effects of transportation activities at the Project site, including site access roads, on-site transportation functions, and interactions with nearby land uses; transportation accidents at site are expected to be conventional in nature, and used nuclear fuel is a stable solid material with well-understood radiological characteristics. Transportation of radioactive materials, including used nuclear fuel, already regularly occurs in Canada and the Project will rely on existing vehicular infrastructure. According to the Canadian Nuclear Safety Commission (CNSC), in 2021/2022 an average of 760,000 radioactive material (RAM) shipments took place each year. Of those shipments, 34,000 were Type B packages (the type of package used to transport used nuclear fuel) were transported in Canada each year. For more information see the Transport of Radioactive Materials in Canada in 2021 and 2022 report (Appendix K) Transportation of used nuclear fuel is subject to a separate federal regulatory framework administered by the CNSC. Transportation activities are regulated through the CNSC's transportation certification and licensing processes, which include requirements for package certification, a transportation licence (including applicable security measures for shipments), and an approved emergency response plan. These requirements are independent of the distance a shipment will travel. Before any shipments of used nuclear fuel could occur, the applicable transport package must be certified by the CNSC, the transportation provider must hold a valid CNSC transportation licence, and emergency response arrangements must be in place and approved, as required. Shipments cannot commence until these regulatory requirements are met, confirming that transportation is safe, secure, and compliant with Canada's nuclear regulatory framework. The philosophy behind the transportation of radioactive materials, including used fuel, is that safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging itself provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Given the robust design and testing requirements for transportation packages, transportation accidents involving used nuclear fuel are expected to be conventional in nature, such as traffic collisions, with no release of radioactive material. Each package provides the same level of safety and is subject to the same level of control and oversight, which is independent of the distance travelled. Concurrent with regulatory engagement to support the regulatory process, the NWMO intends to continue broader communications and engagement with communities to support ongoing dialogue, information sharing, and relationship-building related to its broader work, recognizing that these conversations serve different purposes but remain important to communities.

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NWMO-RSOI-50	Effects of the environment on the project	Seismicity: Concerns that seismic activity (e.g., earthquakes) in the proposed project location could affect the structural stability of design features to contain radioactive waste	The structures, systems and components that are related to the handling, and long-term containment of used fuel at the Project site are being designed to meet all applicable codes and standards related to seismicity. Although CSA N289.1 <i>General requirements for seismic design and qualification of nuclear power plants</i> is largely intended for nuclear power plants, the standard is being considered for applicability, in a graded approach, to the design of specific structures, systems and components of the Project, with consultation and guidance provided by the Canadian Nuclear Safety Commission (CNSC). In addition, the Project site is located in a stable, seismically quiet setting in the Canadian Shield at the heart of the North American continent, away from tectonic plate boundaries and major geological faults. It is considered a craton, which is a large stable block of the earth's crust forming the nucleus of a continent. The Canadian government has maintained a network of monitoring stations that record the location and magnitude of seismic events across the country. In northwestern Ontario, these have been supplemented by the NWMO with additional stations to improve the data coverage and accuracy. To date, in the Canadian Hazard Information Service dataset, there have not been any earthquakes above magnitude 3 utilizing the Nuttli Scale (mN), a magnitude typically felt by most humans, occurring within 50 kilometres (km) from the site. While the Project site is located in a region of low seismic hazard, microseismic monitoring is ongoing to determine if any active faults are present in the region around the Project site. Substantial site characterization work has taken place to date in support of the site selection process, and site characterization activities will continue for most of the Project lifecycle to inform and update key licensing submissions, including safety assessments, for future regulatory approvals and CNSC licences as the Project moves from the site preparation phase, to construction, and to operations. Example of continued site characterization activities include: • Verification of information gathered and analyzed in earlier phases • Establishment of a baseline for future monitoring • Information used in updates to the Project facility post-closure safety case Operational seismic considerations: The used fuel is first handled above ground in the Used Fuel Packaging Plant (UFPP), before being loaded into used fuel containers and transferred underground into the repository. The UFPP is considered a Class IB nuclear facility and will be designed to appropriate seismic codes and standards, commensurate with the design life of the facility, the potential risks present at the facility, and the site-specific Probabilistic Seismic Hazard Assessment (PSHA). Although CSA N289.1 <i>General requirements for seismic design and qualification of nuclear power plants</i> is largely intended for nuclear power plants, the standard is being considered for applicability, in a graded approach, to the design of specific structures, systems and components of the Used Fuel Packaging Plant (UFPP). In addition to seismic design standards, the UFPP will also be designed in accordance with other engineering standards applicable to Class IB nuclear facilities, based on domestic and international best practice. This includes standards related to the containment and control of hazards during accident scenarios (like seismic events), and the supply of backup and emergency power to systems classified as important to safety. Similar design considerations are required for the underground repository, for both operational and post-closure stability during seismic events. Long-term seismic considerations: Seismic influences on the used fuel container are considered in the long-term. Northwestern Ontario is characterized, in general, by low levels of seismic activity as it is within the tectonically stable interior of the North American continent. Large earthquakes will therefore be very unlikely.

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			Earthquakes typically are less destructive at depth than at the surface, diminishing the impact of any seismic activity on a Deep Geological Repository (DGR). The containers are also subject to a range of stress conditions over time. The structural design of the container is determined largely by the requirement to provide adequate mechanical strength throughout its design life. The container is designed to withstand an external isotropic pressure of 45 megapascal (MPa) without gross plastic deformation or buckling. This value will accommodate the buffer swelling load and hydrostatic load exerted at repository depth by a glacier above the repository as discussed below. Other structural effects such as creep (the slow deformation of a material under load) are also considered.
NWMO-RS01-51	Effects of the environment on the project	Long-term containment of waste: Concerns regarding natural events or disasters affecting the structural stability of design features to contain radioactive waste for millions of years e.g., earthquakes, glaciation	The Project contains and isolates the waste over the long-term through the multiple barrier system which consists of the waste, engineered and natural barriers and is based on the safety principles of defence in depth and robustness. Collectively, the multiple barrier system provides a diverse range of mechanisms to facilitate containment and isolation of the waste and to mitigate against expected and unlikely natural events that could occur over the lifetime of the Project. The proposed Project site is within the Revell batholith, a large body of granitoid rock about 2.7 billion years old. The Revell batholith is in the Canadian Shield at the heart of the North American continent and has already experienced multiple glaciations in the past one million years. Glaciation cycles are expected to begin in approximately 50,000 to 60,000 years, and repeat roughly every 120,000 years, based on historical trends. At its maximum development, the glacial ice sheet could be 2 kilometres (km) to 3 km thick above the repository, potentially increasing the hydrostatic pressure at repository depth. The used fuel containers are designed to withstand this additional load while continuing to contain the used fuel. There is also no indication that the proposed Project site will experience extreme rates of erosion, uplift or subsidence that would substantively perturb the geosphere over the next million years. Seismic stresses on the used fuel container are considered in the long-term. Northwestern Ontario is characterized, in general, by low levels of seismic activity as it is within the tectonically stable interior of the North American continent. Large earthquakes will therefore be very unlikely, although an increase in the number and intensity of earthquakes is likely in response to the reduction in loading as ice sheets retreat during glaciation. Earthquakes typically are less destructive at depth than at the surface, diminishing the impact of any seismic activity on a Deep Geological Repository. By placing the used nuclear fuel deep underground, the Project also provides isolation of the wastes from natural events that could occur at the surface (e.g., fire, flood, extreme weather). A Post-Closure Safety Assessment is required to be developed and submitted to the Canadian Nuclear Safety Commission (CNSC) as part of the initial licence application, in accordance with REGDOC-1.2.3 <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>. The assessment is developed in a manner consistent with REGDOC-2.11.1 Volume III, <i>Safety Case for the Disposal of Radioactive Waste</i>, which includes the guidance of the International Atomic Energy Agency's SSR-5 <i>Disposal of Radioactive Waste</i>. The Post-Closure Safety Assessment evaluates the long-term evolution of the entire multiple barrier system, including the waste, the engineered and natural barriers. Natural events, such as glaciations and earthquakes, are incorporated into the modelling and assessment performed in the Post-Closure Safety Assessment. This helps to demonstrate that the Project will continue to contain and isolate the used fuel from the environment even over very long periods of time and through extreme environmental conditions.

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NWMO-RSOI-52	Cumulative Effects	Long-term sustainability: Concerns regarding the ability to communicate hazards to future generations, and to the long-term effects of radioactive waste on future generations	The Project is expected to generate lasting socio-economic and cultural benefits, particularly for municipalities and regional economies. Decommissioning, final closure, and the subsequent institutional control period and eventual release from licensing of the Project site will be governed by the Canadian Nuclear Safety Commission (CNSC) following all associated requirements and will be informed by ongoing engagement with the public and potentially affected Indigenous Nations and communities. The installation of permanent markers to inform future generations of the presence of the sealed repository will be included in the closure plan required by the CNSC. The NWMO will continue engaging with Anishnaabe Peoples of Wabigoon Lake Ojibway Nation and other potentially affected Indigenous Nations and communities on the effective communication of potential long-term effects and hazards to future generations.
NWMO-RSOI-53	Cumulative Effects	Cumulative environmental effects: Concern regarding additional regional land disturbance from the project, the combined pressures of past and existing mining and forestry activities, and the potential for further project related changes to contribute to environmental degradation.	The NWMO understands that concerns have been expressed regarding the potential for long-term or cumulative effects of the Project on the environment. The integrated impact assessment process will consider not only potential effects associated with individual Project activities, as defined within the scope of the, but also how any residual effects may interact with other past, present, and reasonably foreseeable activities. Based on the Impact Assessment Agency of Canada's (IAAC) Policy Framework for Assessing Cumulative Effects under the <i>Impact Assessment Act</i> (IAAC, 2023), the historical context of existing conditions will be considered in the characterization of residual Project effects. If adverse residual effects from the Project are predicted, a cumulative effects assessment will be completed.
NWMO-RSOI-54	Cumulative Effects	Acceptable Risk: Concerns regarding intergenerational changes to acceptable risk related to the project.	Currently, used nuclear fuel is safely stored in licensed interim facilities at reactor sites. While effective in the short term, this approach requires continuous active management and imposes a long-term burden on future generations. The Project will eliminate the need for future generations to actively manage used nuclear fuel, thereby reducing long-term environmental risks and advancing intergenerational equity in managing Canada's nuclear legacy. By proposing the Project, the NWMO is considering intergenerational fairness which considers a balance between the current generation taking responsibility for resolving the problem versus the desire not to constrain future generations by the choices the NWMO makes today. See Table 8-2 in Appendix D of the IPD <i>Choosing a Way Forward</i> for more information on how the NWMO considered intergenerational fairness and risk management related to the Project. By accepting the NWMO's proposal in 2007 the Government of Canada also endorsed NWMO's proposed approach.

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NWMO-RSOI-55	Indigenous engagement	Adequacy of Indigenous engagement: Concerns related to the timing, clarity, accessibility, and transparency of project information and whether engagement activities are meaningful, ongoing, and sufficient to ensure Indigenous Peoples' concerns are identified and addressed throughout the project lifecycle, including opportunities for Indigenous-led assessments and the meaningful consideration of their findings.	The NWMO recognizes the importance of meaningful engagement throughout this regulatory process. Engagement undertaken to support the IPD and initiation of the integrated impact assessment process was designed to meet the objectives of this early regulatory stage, while establishing a foundation for continued engagement as the assessment advances. As the impact assessment progresses, the NWMO remains committed to continued engagement to understand how Indigenous Nations and communities may wish to be involved, how the activities associated with the Project as described in the IPD may potentially affect them (or may not), and how Indigenous perspectives can inform the assessment of potential effects, proposed mitigation measures, and follow-up and monitoring requirements. Through decades of engagement with Canadians and Indigenous Nations and communities, the NWMO has consistently heard that the issue of used nuclear fuel should be addressed now rather than be deferred to future generations. After various options were considered, studied, engaged on (including with Indigenous Nations and communities) and analyzed through a three-year study and dialogue involving Canadians, Indigenous Nations and communities, and technical experts, Adaptive Phased Management using a Deep Geological Repository emerged and was selected by Canada's federal government. Dialogue continues to provide important context and to play an important role as the Adaptive Phase Management is advanced, including as the Project advances into regulatory decision-making. For over 20 years, the NWMO has been engaging with Indigenous Nations and communities, which has informed the development of Adaptive Phased Management and the Project. The Project is intended to provide a safe, long-term solution by containing and isolating used nuclear fuel in a manner that reduces the need for ongoing active management over the long term and limits potential environmental risks, while responding to intergenerational responsibilities associated with Canada's nuclear legacy. Under the <i>Nuclear Fuel Waste Act</i>, the NWMO was required to propose approaches for the management of used nuclear fuel and is now required to implement Canada's selected Adaptive Phase Management plan for the safe, long-term management of used nuclear fuel. The NWMO recognizes that engagement during the integrated impact assessment process for the Deep Geological Repository for Canada's Used Nuclear Fuel Project is intended to support the identification and consideration of potential effects on Indigenous Rights and interests, and to inform the development of mitigation and follow-up measures. The IPD represents the formal initiation of this regulatory process and is an early submission, not the final Integrated Impact Statement and Initial Licence Application used by the regulators for decision-making. As described in Section 3.1 of the IPD, engagement undertaken prior to the NWMO's site selection decision is presented as background context to the Project. Engagement activities prior to site selection were undertaken for various purposes, including to support understanding of the Project and the Adaptive Phased Management approach. Further engagement will be undertaken in connection with the Impact Assessment, Initial Licence Application and subsequent regulatory processes. With submission of the IPD, the Project entered the formal regulatory phase. In advance of the IPD's submission to the Impact Assessment Agency of Canada (IAAC), the NWMO contacted Indigenous Nations and communities identified as potentially affected by the Project, as set out in Section 3.3 of the IPD, to invite participation in the IPD review and to initiate discussions on how they may wish to participate in this regulatory process for the Project. These communications explained the role of the IPD as a first step in the integrated impact assessment process, invited input on the IPD, identified upcoming on information sessions and webinars, and offered to meet with communities to discuss this regulatory process, the IPD, and next steps. The NWMO also advised that multiple additional opportunities to provide input will occur through subsequent regulatory documents and processes. As identified in Section 19 of the IPD, with the application of proposed mitigation measures, the NWMO anticipates limited adverse residual effects on components of the biophysical environment, including water, soils, air, plants, and wildlife, and the human environment, including socio-economic conditions and health. The integrated impact assessment process is intended to be completed on a community-specific basis related to potential meaningful impacts. Ongoing engagement by NWMO with Indigenous Nations and communities will support the identification and assessment of potential effects to

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			Indigenous Rights and interests in a manner that reflects these community-specific considerations and informs decision-making, including appropriate mitigation and follow-up measures to avoid or minimize potential effects of the Project. Concurrent with Indigenous engagement on the Project, the NWMO intends to continue broader communications and engagement with communities to support ongoing dialogue, information sharing, and relationship-building related to its broader work, recognizing that these conversations serve different purposes but remain important to communities.
NWMO-RSOI-56	Indigenous engagement	Consideration of Indigenous Knowledge: Concerns regarding how Indigenous Knowledge, culture, practices, and protocols are considered, incorporated, and reflected in project planning, assessment, and decision-making.	The NWMO respects Indigenous Knowledge and in accordance with our Indigenous Knowledge Policy the NWMO will work with Indigenous Nations and communities to establish protocols respecting the use of Indigenous Knowledge in the regulatory process. In July 2012, the NWMO established the Council of Elders and Youth that grew from the Elders Forum, a previous advisory group that was in place between 2005 and 2012. The Council of Elders and Youth provides ongoing advice to the NWMO to help protect and preserve all creation: air, land, fire, water, plants, medicines, animals and humankind — guided by the seven universal teachings of love, trust, sharing, honesty, humility, respect and wisdom. Guidance from the Council of Elders and Youth informs the NWMO's policies and commitments, which are deeply embedded in all work undertaken at the NWMO, from human resource interview questions to technical studies and assessments for regulatory review. The NWMO publishes an annual Reconciliation report. The latest report, The NWMO 360° Evaluation of Reconciliation Policy 2025 is available on the NWMO website for full transparency on the NWMO's progress towards Reconciliation (NWMO, 2025b). This work provides important background context for the Project. Indigenous Knowledge and Traditional Land Use (IK/TLU) studies specific to the integrated impact assessment process are not yet complete; the NWMO intends to consider Indigenous Knowledge, where appropriate, as the Impact Assessment advances and in a manner that reflects community interests, priorities, and protocols, as well as rigorous, transparent and objective assessment principles. Through this approach, the NWMO intends to ensure that Indigenous Knowledge is considered in a respectful, community-driven manner that supports informed regulatory decision-making. The NWMO is committed to ongoing communication, engagement, and participation with potentially affected Indigenous groups throughout the regulatory processes. This commitment will be carried out in accordance with the NWMO's Reconciliation Policy and Indigenous Knowledge Policy, and through the specific actions and engagement plans described in Section 3.3 of the IPD. The NWMO will continue to build on the relationships that have been developed and is dedicated to cultivating new relationships where engagement has not yet occurred.
NWMO-RSOI-57	Indigenous engagement	Capacity and support for participation: Concerns regarding the availability, adequacy, and equitable distribution of capacity support and resources to enable effective Indigenous participation in engagement and review processes.	With the submission of the IPD, the Project has now entered this formal regulatory decision-making process, which includes new and additional opportunities for potentially affected Indigenous Nations and communities to be involved in the integrated impact assessment process for the Project as described in the IPD. As the Impact Assessment advances, the NWMO welcomes the opportunity to engage with Indigenous Nations and communities potentially affected by the Project to understand how economic, social, and health effects from the Project may be experienced at the community level. As the Impact Assessment Advances, NWMO is committed to working with the Crown to support the participation capacity of Indigenous Nations and communities the Crown identifies as potentially affected by the Project that do not already receive funding under existing agreements. In addition, while specific arrangements are confidential (including due to tailoring based on needs as described above), discussions are underway with several of the Indigenous Nations and communities identified in Section 3.3 of the IPD regarding capacity support and agreements to support their participation in the integrated impact assessment process for the Project.
NWMO-RSOI-58	Physical and cultural heritage	Impacts to culturally and historically significant sites: Concerns that the project may adversely affect physical sites, landscapes, structures, or artifacts of cultural, spiritual, or historical importance.	The NWMO has initiated physical and cultural heritage assessments and will undertake further assessment as the Project advances through the federal Impact Assessment and Initial Licence Application processes. Monitoring and mitigation measures will be refined as the Integrated impact assessment process advances and may evolve based on regulatory engagement, Indigenous engagement outcomes, Indigenous Knowledge, and findings from ongoing studies, ensuring that cultural heritage protection measures remain responsive and appropriate throughout this regulatory process.

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NWMO-RSOI-59	Physical and cultural heritage	Impacts to cultural practices and transmission: Concerns that the project may disrupt cultural practices, traditions, or the intergenerational transmission of culture, language, or Indigenous Knowledge.	The IPD recognizes that potential effects related to cultural continuity and Indigenous Knowledge require further study and engagement, as part of the Integrated Impact Statement and Initial Licence Application. Continued engagement and assessment work will inform the Integrated Impact Statement and support the identification and characterization of potential effects, benefits, and mitigation measures related to cultural continuity. This engagement will also inform significance determinations and the development of appropriate protection and mitigation measures as part of the Impact Assessment for the Project.
NWMO-RSOI-60	Physical and cultural heritage	Long-term or cumulative effects on cultural heritage: Concerns regarding potential long-term or cumulative impacts of the project on physical and cultural heritage.	The integrated impact assessment process will consider potential effects from Project activities, as defined within the scope of the IPD, and how any likely adverse residual Project effects may interact with effects from other past, present, and reasonably foreseeable projects and activities. Through this approach, the NWMO will identify, assesses and address potential long-term and cumulative effects on cultural heritage, including opportunities for positive outcomes as part of the Impact Assessment and subsequent regulatory decision-making. Please see NWMO-RSOI-52, 53 and 54 in this document, for additional responses related to cumulative effects.
NWMO-RSOI-61	Current use of lands and resources	Changes to land and resource use: Concerns related to reduced access to, or availability of, lands, waters, or resources used for traditional, cultural, or subsistence purposes.	The NWMO acknowledges that further engagement and assessment will be undertaken as part of the Integrated Impact Statement phase. This work will include engagement with other potentially affected Indigenous Nations and communities to understand their rights, values, and perspectives related to land and resource use, which may also include consideration of the appropriateness and effectiveness of mitigation measures proposed by the NWMO. This engagement will inform the characterization of residual effects, the refinement of mitigation measures, and the development of follow-up and monitoring programs.
NWMO-RSOI-62	Current use of lands and resources	Impacts to harvesting and travel: Concerns that the project may affect hunting, fishing, trapping, gathering, harvesting, or travel routes used by Indigenous Peoples.	To support the integrated impact assessment process and future permitting and approvals, including approvals related to navigable waters, the NWMO will undertake further work to understand land- and water-based travel routes within the Project site and how they may interact with Project activities. This work will be informed by engagement with Indigenous Nations and communities to confirm the location, use, and importance of travel corridors at the Project site and to identify appropriate mitigation or accommodation measures, where required.

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NWMO-RSOI-63	Current use of lands and resources	Uncertainty related to project effects: Concerns regarding the novel nature of the project, high levels of uncertainty, and limited, inaccurate, or missing baseline data available to accurately predict effects on Indigenous land and resource use.	The IPD represents the formal initiation of a staged regulatory process, and uncertainty at this early stage is expected and addressed through progressively detailed assessment, engagement, and regulatory review. While the Project may seem as though it is a first-of-its-kind project for the long-term management of used nuclear fuel in Canada, it is informed by Canadian and international precedent and subject to rigorous regulatory oversight. Canada has previously undertaken federal environmental assessments of deep geological repository concepts, including the Seaborn Panel review of Atomic Energy of Canada Limited's disposal concept and the environmental assessment of Ontario Power Generation's proposed deep geologic repository (DGR) under the <i>Canadian Environmental Assessment Act, 2012</i>. These reviews concluded that the DGR concept is technically sound and safe, while also reinforcing the importance of Indigenous partnership, informed willingness, and public confidence. Many activities associated with the Project are not novel and are comparable to those undertaken for other major infrastructure projects. These include site preparation, blasting, clearing and grubbing, integrated site water management, water taking and discharge, construction activities, and supporting infrastructure. As recognized by the Impact Assessment Agency of Canada (IAAC) (IAAC, 2026), activities of this nature are well understood and are typically addressed through established, standard mitigation measures. Screening-level assessments for these activities indicate limited residual effects to environmental and human environment components, with further refinement to occur as the assessment advances. Baseline studies and site characterization activities are ongoing and will continue to be advanced to support the Integrated Impact Statement and Initial Licence Application, in accordance with IAAC guidance and Canadian Nuclear Safety Commission (CNSC) requirements. As the Integrated impact assessment process progresses, additional baseline data collection and effects assessment work will be undertaken to progressively reduce uncertainty and support regulatory decision-making. The Project is subject to an integrated impact assessment, including multiple regulatory decision points, opportunities for Indigenous and public participation, and public hearings. Through this staged, transparent, and risk-informed process, supported by established mitigation measures, ongoing studies, Indigenous engagement, and independent regulatory oversight, uncertainty will be progressively reduced and the protection of people, the environment, and Indigenous Rights and interests will be assessed and confirmed before any licensed activities are authorized.
NWMO-RSOI-64	Current use of lands and resources	Cumulative effects on current use: Concerns that the project, in combination with other activities, may further constrain the continued use of lands and resources.	The integrated impact assessment process will consider cumulative effects on current use of lands and resources in accordance with the <i>Impact Assessment Act</i>, including how likely adverse residual effects from Project activities (as defined within the scope of the IPD) may interact with effects from other past, present, and reasonably foreseeable projects and activities (including transportation outside of the scope of the IPD). Based on the Impact Assessment Agency of Canada (IAAC) Policy Framework for Assessing Cumulative Effects under the <i>Impact Assessment Act</i> (IAAC, 2023), the historical context of existing conditions will be considered in the characterization of predicted residual Project effects. If adverse residual effects from the Project are predicted, a cumulative effects assessment will be completed.
NWMO-RSOI-65	Health, social and economic conditions	Health effects: Concerns that the project may adversely affect physical, mental, or emotional health, including exposure to contaminants, changes in air, water, food quality, noise, light, stress, or perceived health risks, including uncertainty due to limited or inadequate baseline health data.	Potential health-related effects to Indigenous Nations and communities from the Project will be further assessed through the Integrated Impact Statement, informed by additional studies and community-specific engagement, and subject to independent regulatory review. For a description of how the NWMO will address potential effects to the physical health of non-Indigenous communities, please see response to NWMO-RSOI-18 in this document.

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NWMO-RSOI-66	Health, social and economic conditions	Community and social well-being: Concerns related to potential effects on community well-being, food security, safety, social cohesion, health outcomes, daily life, population changes, workforce influx, or pressure on housing, services, and infrastructure including uncertainty due to limited or inadequate baseline data.	Potential effects to Indigenous Nations and communities' health and well-being from the Project will be further assessed in the Integrated Impact Statement, informed by additional studies and community-specific engagement, and subject to independent regulatory review. Baseline socio-economic studies are ongoing and will continue to be advanced as part of the impact assessment and initial licence application processes. These studies will inform the assessment of potential interactions between Project activities and community conditions, including potential changes to population, workforce, housing, services, and infrastructure. For a description of how the NWMO will address potential effects of the Project to the physical health of non-Indigenous communities, please see response to NWMO-RSOI-19 in this document. As noted in the answer NWMO-RSOI-18, the NWMO is subject to socio-economic obligations under the <i>Nuclear Fuel Waste Act</i> and is required to report to Canada's Minister of Natural Resources every three years on certain socio-economic conditions related to its activities.
NWMO-RSOI-67	Health, social and economic conditions	Economic opportunities and impacts: Concerns related to project-related employment, training, skill development, business and procurement opportunities, revenue sharing, and job security for Indigenous Peoples, including the adequacy of employment initiatives and measures.	Potential effects from the Project to Indigenous Nations and communities' employment and economic conditions will be further assessed in the Integrated Impact Statement, informed by additional studies and community-specific engagement, and subject to independent regulatory review. Engagement with Indigenous Nations and communities will inform how economic opportunities may be developed and supported in a manner that reflects community interests, priorities, and capacity. This includes discussions related to workforce development, procurement opportunities, and measures to support participation in Project-related economic activities, consistent with applicable regulatory requirements and agreements. For a description of how the NWMO will address potential effects of the Project to employment and economy of non-Indigenous communities, please see response to NWMO-RSOI-18 in this document. As noted in NWMO-RSOI-18, the NWMO is subject to socio-economic obligations under the <i>Nuclear Fuel Waste Act</i> and is required to report to Canada's Minister of Natural Resources every three-years on certain socio-economic conditions related to its activities.
NWMO-RSOI-68	Health, social and economic conditions	Distribution of benefits and burdens: Concerns that economic and social benefits and impacts of the project may not be equitably distributed and could result in economic, social, and health hardships.	With the submission of the IPD, the Project has now entered this formal regulatory decision-making process, which includes new and additional opportunities for potentially affected Indigenous Nations and communities to be involved in the integrated impact assessment process for the Project as described in the IPD. As the integrated impact assessment process advances, the NWMO welcomes the opportunity to engage with Indigenous Nations and communities potentially affected by the Project to understand how economic, social, and health effects from the Project may be experienced at the community level. This engagement will inform the identification and assessment of potential effects, and the identification of mitigation measures to avoid or reduce potential hardships as part of the Integrated Impact Statement and associated regulatory review. For a description of how the NWMO will address potential effects of the Project to economic, social and health conditions of non-Indigenous communities, please see response to NWMO-RSOI-18 in this document. As noted in NWMO-RSOI-18, the NWMO is subject to socio-economic obligations under the <i>Nuclear Fuel Waste Act</i> and is required to report to Canada's Minister of Natural Resources every three-years on certain socio-economic conditions related to its activities.
NWMO-RSOI-69	Rights of Indigenous Peoples	Interference with the exercise of Indigenous Rights: Concerns that the project may interfere with the ability to exercise Indigenous and Treaty rights, including harvesting, cultural practices, governance, or caretaker/stewardship responsibilities.	As the integrated impact assessment process advances, the NWMO will continue engagement with Indigenous Nations and communities potentially affected by the Project to understand how Project activities, as defined in the IPD, may interact with the exercise of Indigenous and Treaty Rights. This engagement will inform the Integrated Impact Statement, including the identification and assessment of potential effects, the identification of appropriate mitigation measures, and the development of follow-up and monitoring commitments. Through this staged, risk-informed, and regulated process, supported by ongoing engagement and independent regulatory oversight, the NWMO intends to ensure that potential effects on the exercise of Indigenous and Treaty Rights are appropriately assessed and addressed before any licensed activities are authorized.

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NWMO-RSOI-70	Rights of Indigenous Peoples	Impacts of environmental change on rights: Concerns that environmental effects of the project, including contamination of land or waterways, may adversely affect the exercise of Indigenous and Treaty rights and that such impacts may not be adequately avoided, mitigated, or accommodated.	Please see response to NWMO-RSOI-69 in this document.
NWMO-RSOI-71	Rights of Indigenous Peoples	Respect for Indigenous authority and jurisdiction: Concerns regarding adequate and appropriate recognition and respect of Indigenous governance, self-determination authority, jurisdiction, and decision-making on their territories and whether their participation and consent are adequately respected.	The NWMO will consider information shared by Indigenous Nations and communities on governance systems in the Integrated Impact Statement. Wabigoon Lake Ojibway Nation (WLON) is exercising its jurisdiction through its Regulatory Assessment and Approvals Process (RAAP) for the Project. The RAAP is WLON's regulatory process grounded in Anishinaabe law, values, and responsibilities, and reflects WLON's authority to review and decide on development within its territory. The NWMO is contractually committed, through the Hosting Agreement, to supporting the Anishinaabe people of WLON in the implementation of the RAAP with respect to the Project
NWMO-RSOI-72	Rights of Indigenous Peoples	Long-term implications for rights: Concerns regarding legacy, long-term or irreversible impacts of the project on the continued exercise of Indigenous and Treaty rights.	Please see response to NWMO-RSOI-69 in this document.

References

The list below consists of references cited throughout the NWMO's Response to the Summary of Issues, including references in Appendix A and Appendix B.

- Canadian Nuclear Safety Commission (CNSC). [Independent Environmental Monitoring Program \(IEMP\)](#). Accessed March 2, 2026.
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- CNSC. [Health Studies](#). Accessed March 2, 2026.
- CNSC. REGDOC-1.2.3, Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository. Available from: <https://www.cnscccsn.gc.ca/eng/acts-and-regulations/regulatory-documents/published/html/regdoc1-2-3/>.
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Appendix A – Response to Summary of Issues Annex A Table

This appendix (Table 2) contains Annex A of the Summary of Issues received from the Impact Assessment Agency of Canada (IAAC) that provided additional comments, guidance and recommendations by IAAC, and the responses from the NWMO to this Annex.

Table 2: Response to Summary of Issues Annex A

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
Annex A NWMO-RSOI-73	Project purpose	Concerns whether the project considers the future value of used nuclear fuel and options for its retrieval should reuse or recycle technologies emerge or better solutions identified.	There is international consensus that deep geological repositories represent the best practice for the long-term management of used nuclear fuel. Countries that reprocess used nuclear fuel, and others that are examining advanced fuel cycles, all have plans to implement deep geological repositories. If Canada chooses to reprocess nuclear fuel in the future, it will be a joint decision by the nuclear energy producers, the associated provincial governments and the federal government. If such a decision were made, the NWMO would work with host communities, utilities and government to safely manage whatever high-level waste resulted from this process. For example, if some used fuel was identified for reprocessing, it could be diverted for that purpose instead of being placed in the deep geological repository and the resulting waste managed by the NWMO.
Annex A NWMO-RSOI-74	Project need	Concerns regarding whether the project is sufficiently justified given perceived risks and uncertainties or whether interim storage is a better option until risk and uncertainties are reduced.	The Project has been developed within an established federal legislative framework, including the <i>Nuclear Fuel Waste Act</i> (NFWA) and the <i>Nuclear Safety and Control Act</i> (NSCA) and is supported by more than two decades of scientific research, technical development, and engagement with Canadians and Indigenous Nations and communities. As stated in the IPD, the NWMO was established in 2002 as a result of a previous federal Seaborn Panel, an Environmental Assessment Panel which reviewed Atomic Energy of Canada Limited's proposed concept for managing used nuclear fuel between 1989 and 1998. The Panel concluded that Canada required a dedicated organization to ensure long-term safety, environmental protection, and public confidence in the management of used nuclear fuel. The NFWA established the legal framework for Canada's long-term management of used nuclear fuel and mandated the NWMO to develop and implement a comprehensive, integrated, and economically sound plan on behalf of Canadians and Indigenous Nations and communities. As described in section seven of the IPD, the need for the Project arises from the requirement to transition from interim storage to a permanent, passive disposal solution that ensures long-term safety, minimizes potential environmental effects, and upholds intergenerational responsibility. The Project also addresses the broader policy objective of sustaining nuclear energy as a low-carbon, reliable power source that contributes to Canada's climate goals. In 2002, the NWMO undertook a comprehensive three-year assessment of alternatives to the Project guided by public consultation and Indigenous engagement, and engagement and is provided in IPD Appendix D: Choosing a Way Forward (NWMO, 2005). The conclusion of this assessment was that the Adaptive Phased Management with a Deep Geological Repository is the most technically and economically feasible option to store used nuclear fuel. Its flexibility, emphasis on safety, and capacity for continuous learning and adaptation ensure that it meets the expectations of both current and future Canadians and Indigenous Nations and communities. In recommending an APM approach, the NWMO proposed a responsible path forward that intends to meet rigorous standards of safety and security for people and the environment. It embraced the precautionary principle and is grounded in concepts of continuous learning and adaptive management. The NWMO believed and still does that this is the strongest possible foundation for managing the risks and uncertainties that are inherent in the very long time-frames over which used nuclear fuel must be managed with care. The NWMO is committed to continued engagement with potentially affected Indigenous Nations and communities, and the public to provide information on the rigorous testing completed to date, and to present the benefits of the Project.
Annex A NWMO-RSOI-75	Project description	Concerns about the adequacy, clarity, and transparency of the Project Description, including how uncertainty, risk, and the effectiveness of proposed mitigation measures are characterized and whether the requirements of the <i>Information and Management of Time Limits</i>	The NWMO is confident that the IPD adequately and transparently met the requirements of Schedule 1 of the <i>Information and Management of Time Limit Regulations</i>. The volume and quality of information presented in the represents over 20 years of technical work and public engagement by the NWMO to inform Project scoping and siting. The information presented in the IPD was prepared in accordance with the following Impact Assessment Agency of Canada (IAAC) guidance documents available at the time of development of the IPD, including: • Guide to Preparing an Initial Project Description and a Detailed Project Description (IAAC, 2025) • Operational Policy Statement: Development of Tailored Impact Statement Guidelines (IAAC, 2022)

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
		Regulations were met.	The Project will be subject to the requirements of not only the <i>Impact Assessment Act</i> (IAA), but also the <i>Nuclear Fuel Waste Act</i> (NFWA) and the <i>Nuclear Safety and Control Act</i> (NSCA), in addition to numerous other federal and provincial licensing and regulatory requirements throughout its life. Under Sections 12 and 18 of the NFWA, the NWMO is required to assess, mitigate, and report on social, economic, and cultural effects for the life of the Project. This includes evaluating the effects of its activities on a community's way of life and its social, cultural, and economic aspirations, and providing effective mitigation measures for these effects. The NWMO has fulfilled this requirement by reporting every three years since 2007, when Adaptive Phased Management was selected as Canada's plan, and by submitting mitigation measures for all phases of the Project to the federal government as part of <i>Choosing a Way Forward</i>. Building on this legislated foundation, the NWMO incorporated these principles into its site selection process and the associated Hosting Agreements for the Project, which further define commitments related to community well-being, economic participation, and cultural sustainability. The integration of requirements under the NFWA with those of the IAA provides opportunities to achieve efficiencies and reduce regulatory duplication, consistent with IAAC's Operational Policy Statement (IAAC, 2022) on proportionality and risk. As the NWMO is already legislatively required under the NFWA to assess, mitigate, and report on social, economic, and cultural effects for the life of the Project, the residual risk of overlap with IAA-mandated factors is considered low. Given these established obligations, the NWMO submits that the prohibition outlined in Section 7 of the IAA should not apply to the ongoing development of social or economic programs with communities. Accordingly, programs are being addressed through the NFWA framework and associated Hosting Agreements, rather than through the scope of factors for the federal integrated impact assessment process. The Canadian Nuclear Safety Commission (CNSC) is the independent federal regulator responsible for overseeing all stages of the Project's lifecycle. The CNSC enforces the NSCA and its supporting regulations, which together regulate all nuclear activities in Canada to protect the environment, human health, and safety. As an integrated impact assessment, a facility for the long-term management of radioactive waste, such as a Deep Geological Repository for used nuclear fuel, must meet the robust and ongoing licensing requirements of the <i>Class I Nuclear Facilities Regulations</i> for its entire lifecycle and each phase of the Project, including public hearings. The CNSC licensing process incorporates the robust management of uncertainty and potential risks into its mandate with the use of precautionary and conservative policies and protocols to protect human and environmental health during each licensing phase. The licensing process will incorporate adaptive management throughout the life of the Project to continuously improving environmental management practices by learning about their outcomes. The NWMO's initial licence application to the CNSC will be submitted together with the Project's Integrated Impact Statement. This application will be prepared in general accordance with the guidance in CNSC REGDOC-1.2.3, <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>. The NWMO's Environmental Protection Program will comply with several CNSC regulatory documents and CSA Group standards and implement the required follow-up and compliance monitoring programs for the life of the Project until closure. Mitigation measures to manage potential effects from nuclear projects in Canada are required to be transparently effective to meet these CNSC compliance monitoring requirements. In addition to these compliance requirements to ensure the effectiveness of implemented mitigation measures for the entire lifecycle of the Project, the Project will be subject to any conditions associated with a decision statement under the IAA and the CNSC licence as well as any conditions associated with the RAAP. The IPD is the first regulatory submission for the Project and is intended to initiate the federal integrated impact assessment process. As described throughout the IPD, known industry standard mitigation measures, regulatory controls, adaptive management, and established best practices were identified. This is presented in similar format to IAAC's list of standard mitigation measures, which was made publicly available in January 2026 following the NWMO's submission of the IPD for the Project in December 2025. The preliminary pathways of change and risk screening presented in the IPD is to help focus the forthcoming Integrated Impact Statement on components where residual effects may be more pronounced, including potential impacts on Indigenous Nations and communities. This screening also provides sufficient information for the IAAC and CNSC to develop Tailored Integrated Impact Statement Guidelines, so that the assessment remains focused, proportionate, and consistent with the principles of the <i>Operational Policy Statement</i>.

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
Annex A NWMO-RS01-76	Indigenous Engagement and the United Nations Declaration on the Rights of Indigenous Peoples:	Need for assessment to include consideration of the United Nations Declaration on the Rights of Indigenous Peoples including the pursuit of free, prior and informed consent.	The primary purpose of the <i>Impact Assessment Act</i> (IAA), "...is to prevent or mitigate significant adverse effects within federal jurisdiction — and significant direct or incidental adverse effects — that may be caused by the carrying out of designated projects". As a result, an Impact Assessment considers the potential for adverse impacts on certain Indigenous Rights. The IAA's preamble indicates that the Government of Canada is committed to implementing the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), which Canada officially endorsed in 2016. Canada's federal government later enacted the <i>United Nations Declaration on the Rights of Indigenous Peoples Act</i> to create a legal framework and process to ensure that federal laws align with UNDRIP. This process is ongoing. Canada's Department of Justice has indicated that the IAAC is committed to implementing the objectives of UNDRIP through the IAA, which was developed to align with UNDRIP.¹ Moreover, Canada's Department of Justice has indicated that IAAC's approach "supports the Government of Canada's aim to secure free, prior and informed consent throughout the impact assessment. The approach to achieving free, prior and informed consent is based on ensuring meaningful and effective participation of Indigenous peoples from the outset and will vary based on the project impacts and the interests of Indigenous peoples in the vicinity of the project."² For context, UNDRIP is an international human rights instrument that recognizes existing rights and principles from certain other United Nations' instruments, setting out collective and individual rights of Indigenous peoples as well as how those rights are to be interpreted and applied in light of other rights and principles. The interpretation and application of UNDRIP, including free, prior and informed consent (FPIC), in Canada is evolving. When engaged under UNDRIP, FPIC plays a role in guiding States (such as, Canada) and affected Indigenous peoples. Given an impact assessment considers a project's potential effects on certain Indigenous Rights, consideration of UNDRIP including the pursuit of FPIC is part of such an assessment.
Annex A NWMO-RS01-77	Public Engagement and Communication	Concerns regarding the transparency of historic engagement and the need for ongoing, public engagement to ensure public concerns, including those proximate and downstream of the project are meaningfully addressed. Need for additional information on planned public engagement, with plans for clear, accessible, plain-language, and inclusive communications, particularly regarding safety, project scope, risks, and long-term impacts.	In addition to engagement with Anishinaabe people of Wabigoon Lake Ojibway Nation (WLON) and other Indigenous Nations and communities, the NWMO has engaged extensively with the public and interested parties, such as municipalities, businesses, service providers, and environmental organizations, for over two decades. The site selection process for the Project began in 2010, with 22 communities expressing proactive interest by 2012. The objective of public engagement at this stage was to raise awareness and provide balanced, objective information to the public and interested parties. Along the way, many of the interested communities entered Learn More agreements with the NWMO, which facilitated the public engagement efforts and provided communities with additional capacity to learn about the Project. Part of these site selection efforts included the establishment of Community Liaison Committees (CLC) with respect to the area surrounding the potential Project site. The CLCs were created as committees of the local municipal council. They were comprised of community members who met regularly on many topics related to the NWMO's work, including information presented by the NWMO staff and international experts, on matters related to hosting a DGR. In 2020, the NWMO narrowed the focus to two potential host sites in Ontario: the WLON and Ignace area and the Saugeen Ojibway Nation-South Bruce area. Together, working with the municipalities and Nations, the NWMO assessed each site for its potential to meet the Project's robust safety requirements and to build supportive and resilient partnerships. At this stage, the community-driven engagement was tailored to address each community's needs, providing the necessary information for informed decision making, continuing to raise awareness, and informing the broader public. As a result of the input received, the site selection process culminated in the selection of the WLON and Ignace area as the host site for the Project.

¹ Canada, Department of Justice, *Implementing the United Nations Declaration on the Rights of Indigenous Peoples* (n.d.) at p 1.

² Canada, Department of Justice, *Implementing the United Nations Declaration on the Rights of Indigenous Peoples* (n.d.) at p 3.

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
			Following the site selection announcement, the NWMO's engagement activities with the public and interested parties transitioned toward discussions on the IPD and the regulatory decision-making processes that would apply to the Project, specifically the Integrated Impact Statement and Initial Licence application to the Impact Assessment Agency of Canada and the Canadian Nuclear Safety Commission (CNSC). To support this engagement, the NWMO developed plain-language materials summarizing an early draft of the IPD. These materials were made publicly available through the NWMO's website, local offices, and in print at community events. The summary included information about the Project's purpose and benefits, key design features, baseline data collection programs completed to date, and preliminary conclusions regarding potential effects. During this phase, the NWMO held a total of eight engagement events with the public, including four in-person sessions in Ignace, two in-person sessions in Dryden, and two virtual events. Details of these activities are provided in Appendix B of the IPD. Engagement, participation, and communication are embedded across all statutory, regulatory, and oversight frameworks governing the Project as described in Section I of the IPD. These obligations are established under the <i>Nuclear Fuel Waste Act</i> (NFWA), the <i>Nuclear Safety and Control Act</i> (NSCA) and the Hosting Agreements with the Township of Ignace (Appendix C) and the Anishinaabe peoples of WLON. The NFWA requires ongoing dialogue with communities, transparent reporting on social and economic effects, and independent review through the NWMO's Advisory Council. Under the NSCA, the NWMO will maintain a Public Information Program and Disclosure Protocol in accordance with CNSC REGDOC-3.2.1, ensuring timely and accessible communication about Project safety and performance. The Hosting Agreement with the Township of Ignace (Appendix C) outlines formal engagement obligations for both parties, including participation in regulatory reviews, technical studies, and public hearings. The NWMO will continue to engage transparently and inclusively throughout all phases of regulatory decisionmaking. The NWMO will continue open and transparent engagement with the public and interested parties throughout the regulatory decision-making process. Building on the engagement completed during site selection and development of the IPD, future engagement will focus on sharing information, obtaining input and ensuring accessibility at key Project milestones. As the Integrated impact assessment and initial licence processes advance, the NWMO will continue to provide plain-language materials such as fact sheets, summaries, and online content, and will host public sessions to discuss Project progress, potential effects, and mitigation measures. Engagement methods will be regularly reviewed and adjusted based on feedback to ensure inclusiveness and effectiveness.
Annex A NWMO-RSOI-78	Monitoring health impacts	Monitoring health impacts Need more information on who would be monitoring the health impacts of the DGR to be consistent with CNSC regulatory expectations for radiation protection and environmental health oversight.	The NWMO will meet all regulatory requirements from the Canadian Nuclear Safety Commission (CNSC), as described below. Environmental protection for nuclear facilities and activities is done in accordance with the <i>Nuclear Safety and Control Act</i> and the regulations made under it. This legislation includes provisions to ensure that licensees are meeting the CNSC's mandate to protect the environment and the health, safety and security of persons. The CNSC requires the environmental effects of all nuclear facilities or activities to be considered and evaluated when licensing decisions are made. Further information on the CNSC regulatory requirements are found here: Environmental protection. The CNSC also has its Independent Environmental Monitoring Program (IEMP). The IEMP complements existing and ongoing compliance activities to verify that the public and environment around CNSC-regulated nuclear facilities are not adversely affected by releases to the environment. This verification is achieved through independent sampling and analysis by the CNSC. The CNSC also maintains information for the public and Indigenous Nations and communities on their health research programs, which informs their regulatory framework, found here: Health studies. As the lifecycle regulator for the Project, the CNSC will conduct ongoing compliance verifications to verify that the NWMO continues to meet all regulatory requirements.

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
Annex A NWMO-RS01-79	Radiation exposure limits	Concerns that current exposure limits for radiation are unsafe.	The International Commission on Radiological Protection (ICRP) is an independent, international organisation that advances for the public benefit the science of radiological protection, in particular by providing recommendations and guidance on all aspects of protection against ionising radiation. The ICRP is a not-for-profit organization, and a community of about 350 globally recognized experts in radiological protection science, policy, and practice from around 40 countries. The ICRP has published well over one hundred publications on all aspects of radiological protection. It offers its recommendations to regulatory and advisory agencies and provides advice the intended to be of help to management and professional staff with responsibilities for radiological protection. Legislation in most countries adheres closely to ICRP recommendations. The International Atomic Energy Agency (IAEA) <i>International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources</i> is based heavily on ICRP recommendations. Many IAEA guidance and requirement documents reference ICRP reports as fundamental research and reference material. The Canadian Nuclear Safety Commission (CNSC) <i>Radiation Protection Regulations</i> are based on the work of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the ICRP, and the IAEA. Therefore, the CNSC <i>Radiation Protection Regulations</i> are based on the best available international science and research. CNSC's own regulations are consistent with international best practices, and radiation protection limits are derived using the most conservative proposed dose-risk models, known as the Linear-Non-Threshold (LNT) model. This model postulates that all radiation dose received increases the risk of cancer or hereditary disease, incrementally in a linear fashion. The model is largely based off atomic bomb survivors, where higher doses resulted in proportionally higher rates of cancer. The relationship between very high, instantaneous doses and cancer rate is also applied to very low doses delivered over long periods of time, resulting in a dose model that likely over-estimates the risk of low doses of radiation. For this reason, it is widely accepted that the public and worker radiation dose limits are already very conservative.
Annex A NWMO-RS01-80	Monitoring of effects during construction and operation	Concerns regarding effects of the project to communities close by and request for monitoring of effects during construction and operations on air, water, soil and from blasting	The NWMO's Environmental Protection Program, which includes an adaptive management component, will comply with Canadian Nuclear Safety Commission (CNSC) licensing and federal/provincial permitting requirements informed by engagement with Ignace, Wabigoon Lake Ojibway Nation (WLON), and other potentially affected Indigenous Nations and communities. The CNSC is the independent federal regulator responsible for overseeing all stages of the Project's lifecycle. The CNSC enforces the <i>Nuclear Safety and Control Act</i> (NSCA) and its supporting regulations, which together regulate all nuclear activities in Canada to protect the environment, human health, and safety. As an integrated impact assessment, a facility for the long-term management of radioactive waste, such as a Deep Geological Repository for used nuclear fuel, must meet the robust and ongoing licensing requirements of the Class I Nuclear Facilities Regulations for its entire lifecycle and each phase of the Project. The CNSC licensing process incorporates the robust management of uncertainty and potential risks into its mandate with the use of precautionary and conservative policies and protocols to protect human and environmental health during each licensing phase. The licensing process will incorporate adaptive management throughout the life of the Project to continuously improve environmental management practices by learning about their outcomes. The NWMO's initial licence application to the CNSC will be submitted together with the Project's Integrated Impact Statement. This application will be prepared in general accordance with the guidance in CNSC REGDOC-1.2.3, <i>Licence Application Guide: Licence to Prepare Site for a Deep Geological Repository</i>. The NWMO's Environmental Protection Program will comply with several CNSC regulatory documents and CSA Group standards and implement the required follow-up and compliance monitoring programs for the life of the Project until closure, including monitoring of air, water and soil. Furthermore, a Human Health and Ecological Risk Assessment (HHERA) will be completed to inform the Integrated Impact Statement and Initial Licence Application. Ecological components and wildlife receptors will be selected for the HHERA based on feedback and engagement from potentially affected Indigenous Nations and communities and the public. Both radiological and contaminants of potential concern (including the potential for bioaccumulation) pathways via air, soil, and water will be conservatively modelled as part of this HHERA to predict potential effects to ecological receptors, such as wildlife, based on a calculation of

Response Identifier	Comment Topic	Additional Comments, Guidance and Recommendations	NWMO Response
			dose and risk. The HHERA will be reviewed by the CNSC under the NSCA and CNSC REGDOC-2.9.1 and will confirm that mitigation measures will avoid or minimize potential effects. The HHERA will be updated every five years throughout the Project's lifespan. Mitigation measures to manage potential effects from nuclear projects in Canada are required to be transparently effective to meet these CNSC compliance monitoring requirements. In addition to these compliance requirements to ensure the effectiveness of implemented mitigation measures for the entire lifecycle of the Project, the Project will be subject to any conditions associated with an Impact Assessment Agency of Canada (IAAC) decision statement, as well as conditions associated with any approvals by the Wabigoon Lake Ojibway Nation Regulatory Assessment and Approval Process (as applicable).

Appendix B – Response to CNSC Comments Table

This appendix (Table 3) contains comments received from the Canadian Nuclear Safety Commission (CNSC), and responses from the NWMO to these comments.

Table 3: Response to CNSC Comments

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
CNSC-1	Fire Response (Section 15.7.1) Canadian Codes and Standards	The IPD identifies challenges in the fire response capabilities of nearby communities. <i>CSA N393- Fire protection for facilities that process, handle, or store nuclear substances</i> specifies the fire response requirements that need to be met for the proposed project. The Nuclear Waste Management Organization (NWMO) will need to ensure that fire response capabilities at the site meet the requirements of <i>CSA N393</i> and that this is clearly identified in the Impact Statement (IS).	The NWMO understands and recognizes that the fire response capabilities of the site are expected to meet the requirements of <i>CSA N393- Fire protection for facilities that process, handle, or store nuclear substances</i>. It is worth noting that there are no structures, systems, or components included in the scope of the Initial Licence that are expected to process, handle, or store nuclear materials. Structures, systems, or components that will process, handle, or store nuclear materials are expected to be included in the scope of a future regulatory approvals process. As a result, <i>CSA N393</i> will be applied in a graded approach, as the activities on the site evolve. Further information on this topic will be included the Integrated Impact Statement and Initial Licence Application.
CNSC-2	Emergency Response	The IPD indicated that there will be underground work required for this project during future phases, which requires specialized emergency response teams to always be present during underground work. The NWMO must consider the requirement of having an onsite emergency response team that is trained to respond to underground emergencies and ensure it is clearly indicated in the IS.	The NWMO understands and recognizes that underground work requires specialized emergency response teams to be present. This information will be clearly indicated in the Integrated Impact Statement and Initial Licence Application. The NWMO's overall Emergency Response Program itself is developed in accordance with REGDOC-2-10-1 <i>Nuclear Emergency Preparedness and Response</i>. At this time, there are no underground works included in the scope of the Initial Licence. The Emergency Response Program and its associated plans and procedures will be developed to be commensurate with the proposed licensed activities, and will be revised in the future to accommodate underground works, as appropriate.
CNSC-3	Canadian Codes and Standards	Several codes and standards and regulatory documents (REGDOCs) referenced throughout the IPD are not the latest published revisions. The NWMO is requested to ensure the IS references the latest published versions.	The NWMO recognizes that codes, standards, and Canadian Nuclear Safety Commission (CNSC) REGDOCs may be revised and issued during the development of the Integrated Impact Statement and Initial Licence Application. The work performed by and under the NWMO is expected to use the latest published versions of codes, standards, and REGDOCs applicable to the project. The Integrated Impact Statement and Initial Licence Application will reference these codes, standards, and REGDOCs as appropriate.
CNSC-4	Canadian Codes and Standards	There is no information in the IPD about <i>CSA N292.7-Deep geological disposal of radioactive waste and irradiated fuel</i> . This standard should be included in the IS as a key topic-specific Canadian standard on geological disposal.	The NWMO recognizes the importance and applicability of <i>CSA N292.7- Deep geological disposal of radioactive waste and irradiated fuel</i> with respect to Canada and the DGR Project. The standard is being used to guide general requirements of the Project, including for Indigenous and public engagement, site evaluation, design, monitoring and surveillance, safety assessment, construction, commissioning, operations, closure and institutional controls. Reference to this standard will be included in the Integrated Impact Statement and Initial Licence Application.

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
CNSC-5	Management Systems (Section 7 of the licensing appendix)	The IPD does not give any information as to whether the NWMO's management system is integrated with the environmental management system, water management system, and so on. <i>CSA N286-12 - Management system requirements for nuclear facilities</i> integrates the requirements from management system standards for health, safety, environment, security, economics, and quality. This information should be provided in the IS.	The NWMO recognizes that its management system must be integrated and must meet the requirements of CSA N286-12, with additional guidance and requirements, as provided in REGDOC-2.1.1 <i>Management System</i>. More information about the NWMO's management system programs, including the environmental management system (and subsequent groundwater protection plans and effluent and emissions control monitoring plans) will be included in the Integrated Impact Statement and Initial Licence Application.
CNSC-6	Management Systems (Section 7 of the licensing appendix)	The proposed project needs to be managed as any industrial project (organization structures, management functions, pricing, cost control, risk management, contract management, quality management, project type, etc.) following good practices in the project management handbook. The IPD does not provide any information on how the NWMO will manage the contract (e.g., engineering, procurement and construction, integrated project delivery, etc.). If the NWMO has not decided on the project contract type, the IS should indicate that the NWMO will do so in the future.	The NWMO, as the owner of the project, has procured WSP Canada Inc., Peter Kiewit Sons ULC (Kiewit), Hatch Ltd., Thyssen Mining Construction of Canada Ltd. and Kinectrics Inc. The chosen companies will work on facility infrastructure design and engineering, construction planning, mine design, mine construction, nuclear management advising and nuclear systems and facilities design. The NWMO is using an Integrated Project Delivery model to design and build the Project. The companies and the NWMO will work as one team, co-located to move the Project forward. This approach encourages trust and open communication among all parties, putting what is best for the Project first by enabling collaboration between the NWMO and the selected companies. All companies involved, including the NWMO, will work hand-in-hand throughout the entirety of the process. This integrated and collaborative contracting approach is ideal for the Project with its inclusion of input from our host communities, the regulators, and other interested parties. More information is available on the following NWMO webpage: The Nuclear Waste Management Organization chooses vendors to design and plan Canada's deep geological repository (NWMO, 2025c).
CNSC-7	Sequencing of Ongoing Characterization Work (Sections 9 and 14)	In Section 9.4.2: Listing of Site Preparation Phase Activities of the IPD, site characterization is not included in the list of site preparation activities (though it is mentioned in Section 9.3: Preliminary List of Project Activities Prior to Initial Licence). This raises the question, how will the NWMO communicate with the CNSC and other interested parties on this issue? Dialogue and transparency on this topic should be clarified in the IS. Section 14: Biophysical Environment of the IPD provided more information on ongoing work (including geological site characterization), acknowledged that some activities would be carried out to meet the expectations of a licence application, and that some would be for future licensing stages. It is essential that the NWMO engage with CNSC staff on elements related to ongoing site characterization, the purpose, timing, and location of additional boreholes. NWMO documentation (and statements) about site suitability (e.g., page 99 within Section 14: Biophysical Environment) still need to undergo review and assessment by CNSC staff (this includes the approaches to defining and managing uncertainties).	The NWMO will continue ongoing dialogue and engagement with the public, regulators, and Indigenous Nations and communities potentially affected by the Project, including on the topic of ongoing site characterization work. The NWMO will maintain a Public Information Program and Disclosure Protocol in accordance with CNSC REGDOC-3.2.1, <i>Public Information and Disclosure</i>, ensuring timely and accessible communication about Project safety and performance. This program will be included in the Integrated Impact Statement and Initial Licence Application. The NWMO recognizes the importance of ongoing dialogue and engagement with CNSC staff, especially regarding elements related to ongoing site characterization. The NWMO also recognizes that the overall suitability of the site is subject to review and assessment by CNSC staff. The integrated Impact Statement and Initial Licence Application will include updated information with respect to any temporary facilities/infrastructure related to site evaluation/characterization. Existing and future temporary infrastructure at the site may include the following: 1. Seismic monitoring stations

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		While it is clear that additional site characterization activities are underway, it is not clear in Section 9: Activities, Infrastructure, Structures and Physical Works (notably on page 44) of the IPD whether there would be temporary facilities/infrastructure related to site evaluation/characterization (e.g., borehole drilling, core storage, etc.). This should be clarified in the IS.	2. Long term groundwater monitoring stations 3. Long-term ground motion Global Navigation Satellite System (real-time kinematic GPS) stations 4. Additional boreholes, both shallow and deep 5. Borehole collar housing
CNSC-8	Multi-Barrier System (Section 9)	Activities at the Underground Demonstration Facility that are planned to start after its construction are important verification activities for the long-term performance of the multi-barrier system. They should be included as major activities in the appropriate sections of the IS. The specific activities to be performed should be proposed to the CNSC and the results should be formally communicated to the CNSC at key milestones throughout the process.	The NWMO recognizes the importance of the Underground Demonstration Facility with respect to geoscience verification, demonstration of emplacement room excavation methods, used fuel container emplacement procedures, and to perform research on the long-term performance of the multiple barrier system. A discussion of these activities will be included in the Integrated Impact Statement and Initial Licence Application, to support a description of the complete lifecycle of the Project. It is worth noting that there are no underground works proposed in the scope of the Initial Licence (as per Table 9.2 of the IPD), and therefore details of the Underground Demonstration Facility are being developed to support future regulatory approvals. The specific activities to be performed will be proposed to the CNSC staff and the results will be communicated at key milestones throughout the regulatory process.
CNSC-9	Security Processes (Table 18.1)	The NWMO has not listed REGDOC-2.12.1, <i>High Security Facilities, Volume I: Nuclear Response Force, Version 2</i> and REGDOC-2.12.1, <i>High-Security Facilities, Volume II: Criteria for Nuclear Security Systems and Devices</i> in the IPD as applicable to the project. These documents contain the requirements and guidance for establishing a nuclear response force, and the systems and devices for the protected area and search and screening. While it is not expected that the details of security processes and equipment would be discussed in the submission due to the confidential nature of the content, CNSC staff request clarification as to how these documents will be considered in the planning of security processes.	The NWMO recognizes that both REGDOC-2.12.1 Volume I <i>High Security Facilities, Volume I: Nuclear Response Force</i> and REGDOC-2.12.1 Volume II <i>Criteria for Nuclear Security Systems and Devices</i> will apply, either wholly or in part, to the DGR facility during the operation phase of the Project, when radioactive material and used fuel is present. The NWMO also recognizes that portions of REGDOC-2.12.1 Volume II are relevant to the security design of nuclear facilities and the systems and devices used in the protected area, and are therefore relevant to obtain regulatory approvals for the construction phase. The NWMO intends to engage with CNSC staff early during the development of specific security processes and systems, to ensure that requirements of REGDOC-2.12.1 Volume I and REGDOC-2.12.1 Volume II are being met. A portion of this regulatory engagement is expected to inform the physical design of the nuclear facilities, supporting a Licence to Construct. Regulatory engagement is expected to inform nuclear security processes, systems and procedures, which would support the Licence to Operate. The NWMO will also consider collaborating with other nuclear licensees such as Ontario Power Generation (OPG), Bruce Power, and Canadian Nuclear Laboratories (CNL), to help benchmark and develop the NWMO security programs and processes.

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CNSC-10	Approvals and Permits (Section 18)	From the documentation submitted, CNSC staff were unable to identify any information regarding the approval processes with appropriate jurisdictions for civil works and civil structures (e.g., similar to city and/or provincial approval processes for conventional building permits) other than the general statement that necessary permits and approvals would be obtained prior to the applicable physical work being performed at the site, alongside the high level information provided in Section 18: Indigenous, Federal and Provincial Environmental Approvals in the IPD. The NWMO is requested to explain the process to obtain building/construction permits from the appropriate authorities and jurisdictions. The NWMO will further be requested to provide evidence that the permits are being requested and obtained as required.	Section 18 of the IPD focused on environmental permits and approvals that may be required by provincial and federal authorities. As the Project site is within an unorganized area, the exact process to obtain building/construction permits from the appropriate authorities and jurisdictions is expected to be determined through the regulatory process, in consultation with the Impact Assessment Agency of Canada (IAAC), the CNSC, and any other authority having jurisdiction.
CNSC-11	Safeguards (Table 2 of the licensing appendix)	A reduced number of safeguards requirements from REGDOC-2.13.1 are applicable to a DGR for an initial licence appliance and phase. This should be clearly identified within the IS. There are no safeguards requirements during this "pre-initial licence" phase, but the CNSC encourages engagement between the CNSC, the NWMO, and the International Atomic Energy Agency on potential safeguards measures for the future facility early in the design process.	The NWMO recognizes the applicability of REGDOC-2.13.1 <i>Safeguards and Nuclear Material Accountancy</i>, with respect to safeguard requirements for the DGR, and will clearly identify this within the Integrated Impact Statement and Initial Licence Application. The NWMO intends to engage with the CNSC and the International Atomic Energy Agency on potential safeguards measures for the future facility early in the design process. Additional discussion related to safeguards is provided in NWMO response NWMO-RSOI-37 in Table 1.
CNSC-13	Key Issues Raised in Engagement Activities (Section 3.2)	The NWMO should ensure that built-in linkages are captured regarding Indigenous engagement key issues (e.g., protect water, land, air, wildlife; involve Indigenous people in data collection; habitat disturbance) and environmental protection requirements in the IS, where feasible (e.g., environmental and emissions reporting).	The NWMO agrees that clear linkages between Indigenous engagement priorities and environmental protection requirements are important to a credible Impact Statement. As the Impact Assessment advances, the Impact Statement will explicitly describe how key issues raised through Indigenous engagement, including protection of water, land, air, wildlife, habitat disturbance, and involvement of Indigenous Peoples in data collection, are considered within the assessment of valued components, the identification of potential effects, and the development of mitigation, follow-up, and monitoring measures. This includes linking community-specific concerns and Indigenous Knowledge, where provided in accordance with community priorities and protocols, to environmental protection measures, monitoring programs, and reporting commitments, including environmental and emissions monitoring. Engagement with Indigenous Nations and communities during the Impact Assessment is intended to support the identification of these linkages on a community-specific basis and to inform how potential effects on the biophysical and human environment interface with Indigenous Rights, interests, and values. These linkages will be documented in the Impact Statement and refined as engagement and assessment work progresses. The NWMO welcomes the opportunity to engage with any potentially affected Indigenous Nations or communities, as part of the regulatory processes. This engagement will focus on understanding how site activities may interact with the biophysical and human environment in ways that are relevant to that community, including through participation in baseline programs, input to effects assessments, and consideration of appropriate mitigation measures, so that the assessment of Project effects is meaningful and informed.

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CNSC-17	Environmental Risk Assessment	Ecosystem Services are mentioned in Section 14 of the IPD and in earlier NWMO reports, but plans on how to use this information to further the assessment of risk to environment and/or humans should be clarified in the IS.	The use of the term "ecosystem services" is not expected to continue into the Integrated Impact Statement and Initial Licence Application. In future statements on this topic, the NWMO would instead use a description like the following: "For semi-aquatic mammals, future years of study will focus on determining the numbers, locations, and habitat use (e.g., use of aquatic areas, wetlands, ponds) of beavers in the study area, including related to and possibly additional semi-aquatic mammal species, where warranted."
CNSC-18	Population and Demographics (Section 15.5)	Three different scenarios are intended to be used to represent the possible range of human population growth. The optimistic growth scenario is intended to serve as an upper bound to population growth and would require substantial in-migration to reach this level of population, but is there a risk of a community arising in closer proximity to the project? If surrounding land is Crown owned, there will be more control. The NWMO should include these considerations when assessing potential future development in nearest publicly owned lands in the IS. Given that the proposed project can also be expected to provide economic benefits to local communities, the IS could consider including community assessments at increasing distance from project to evaluate this impact over time and/or comparison of community benefits with those of mining industry to assist with extrapolation.	The NWMO acknowledges the reviewer's comment regarding potential additional or expanded community-level socio-economic assessments, such as assessments at increasing distance from the Project or comparisons to the mining industry. Based on the existing regulatory oversight of the Project by the <i>Nuclear Fuel Waste Act</i>, the NWMO does not anticipate these additional analyses will be required as part of the Impact Statement. The potential for used nuclear fuel management to affect socio-economic and cultural conditions has been anticipated and regulated for more than two decades under the <i>Nuclear Fuel Waste Act</i>. In developing and assessing options for the long-term management of used nuclear fuel, the NWMO was required to consider ethical, social, and economic factors and to develop implementation plans describing how significant socio-economic effects on communities' ways of life and social, cultural, and economic aspirations would be avoided or minimized. These considerations and plans informed the Government of Canada's 2007 decision to select Adaptive Phased Management as Canada's long-term plan for used nuclear fuel, as documented in the NWMO study Choosing a Way Forward. Since the federal government's selection of Adaptive Phased Management, the NWMO has been subject to an ongoing, legislated socio-economic oversight regime. The <i>Nuclear Fuel Waste Act</i> requires the NWMO to prepare and submit a public report every three years that includes an analysis of any significant socio-economic effects of its activities, as well as the results of public consultations. These reports are reviewed by the Minister of Natural Resources and tabled in Parliament, providing regular oversight and accountability for socio-economic performance over the life of the program. This rolling, life-of-project reporting framework is more appropriate and reliable than attempting to predict socio-economic conditions over very long time horizons through one-time or extrapolated assessments, particularly given the duration of the Project. It also ensures that socio-economic considerations remain subject to ongoing federal oversight and adjustment, as required. As a result, the NWMO is already subject to a legally binding regulatory framework governing socio-economic and cultural conditions. Duplicative or parallel socio-economic assessments within the Impact Statement are unnecessary and could create inconsistency with the <i>Nuclear Fuel Waste Act</i>. The Integrated Impact Statement and Initial Licence Application will therefore rely on this existing statutory framework, while continuing to meet all requirements of the integrated impact assessment process.

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CNSC-19	Valued Components (Table 19.1)	In Table 19.1 of the IPD, the measurement indicators and assessment endpoints for Indigenous peoples are "to be defined by each potentially impacted Indigenous Nations and communities". Recommend adding clarification in the IS for the approach if no concerns or alternatives are raised during engagement and consultation.	The Integrated Impact Statement and Initial Licence Application will address the approach to the selection of measurement indicators and assessment endpoints in the event that no concerns or alternatives are raised during engagement and consultation.
CNSC-20	Pathways of Effects (Table 19.4)	Table 19.4 in the IPD should list "Pathway of Change" in first column since current wording in first column "Project Components/Activities" appears repetitive, but reason why isn't obvious until you scan to third column in table (i.e., considered for a different pathway). Purpose of table is also as titled "Pathways of Change Screening....". This should be corrected within the IS.	The structure of equivalent tables in the Integrated Impact Statement and Initial Licence Application will be revised for clarity on this topic.
CNSC-21	Pathways of Effects (Section 19.2.3.10.1)	In the IPD's terrestrial pathways of change screening, the carnivores and moose are the only large terrestrial mammals considered, but other large terrestrial omnivores and herbivores such as deer (herbivore) and bear (omnivore) would also be present. White-tailed deer are mentioned in Section 14.10 in the IPD, but then not discussed further with no rationale provided for exclusion from assessment. There is no mention of bear in Section 14.10 of the IPD. Please clarify rationale for inclusion and/or exclusion of large terrestrial mammals considered in the IS.	The rationale for inclusion and/or exclusion of large terrestrial mammals will be clarified in the Integrated Impact Statement and Initial Licence Application.
CNSC-22	Emissions (Table 23.1)	Table 23.1 in the IPD contains list of potential waste and emissions. The "Radioactive Waste" category contains "Spills from equipment and machinery" during all project phases, but no spills are captured under "Non-Radioactive Waste". There should also be non-radioactive spills considered during site preparation or construction. This should be corrected/clarified within the IS.	The NWMO agrees that there is a potential for non-radioactive spills to occur during the site preparation and construction phases. This table, or its equivalent, will be revised in the Integrated Impact Statement and Initial Licence Application to reflect this omission.
CNSC-23	Canadian Codes and Standards (Section 24)	In Section 24 of the IPD, there is mention of the version for CSA N288.8-17, but not for CSA N288.4, N288.5 or N288.7. In the IS, ensure there is consistency in how CSA standards are reported throughout the document.	The NWMO will report CSA standards in a consistent manner throughout the Integrated Impact Statement and Initial Licence Application.
CNSC-24	Interactions with the CNSC	In the IPD, there is no mention of dialogue with the CNSC. Dialogue with the CNSC from the inception of the proposed project enabled pre-licensing activities to be conducted that include monitoring NWMO's siting/ research activities to verify that they meet CNSC's expectations and best international practices, conducting independent research focusing on safety, developing regulatory documents to define requirements, and clarifying regulatory expectations. This information should be added in the IS where appropriate.	The NWMO recognizes the importance of an ongoing dialogue with the CNSC staff with respect to the development of the DGR project. This is especially important to the siting and research activities to allow the CNSC to verify that expectations and best international practices are being met. The NWMO recognizes that this ongoing dialogue allows the CNSC to conduct independent research with a focus on safety, the development of regulatory documents to define requirements, and to clarify regulatory expectations. The Integrated Impact Statement and Initial Licence Application will discuss this dialogue and its impacts on Project development.

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CNSC-25	Transportation (Section 9.3)	The IPD states that the proposed project does not include transportation of used fuel from reactor sites to the project beyond primary and secondary access roads at the proposed project site as this is regulated separately under CNSC certification and uses existing transportation infrastructure. Although CNSC staff agrees that the transport of nuclear substances is regulated by the CNSC and Transport Canada, this needs further justification considering that the number of shipments each year of nuclear fuel that will take place for this project, if approved, will be significantly higher than the current transportation of used fuel taking place in Canada. NWMO's web site references a generic study conducted on dose rate assessment to public and workers for different modes of transport of used fuel. However, no reference is made to these reports in this document. The NWMO is requested to provide additional justification for how the current regulations ensure that there will be insignificant impact on the environment from the proposed project and confirm if the results of these previous studies remain valid for the proposed project.	The NWMO's responses NWMO-RSOI-39 through NWMO-RSOI-49 in Table 1 include a comprehensive discussion about the transportation of used fuel in Canada. Excerpts from those responses are included here. <u>Current transportation regulations</u> As outlined in the IPD, the transportation of used fuel from fuel owner sites to the Project site, beyond the primary and secondary access roads at the site, is addressed through a separate federal regulatory framework. That transportation is regulated through the CNSC transportation package certification and transport licensing processes and Transport Canada's (TC) <i>Transportation of Dangerous Goods Regulations</i> and relies on existing transportation infrastructure. The CNSC and TC regulations are informed by the International Atomic Energy Agency's transport guidance and requirements and are therefore aligned with international best practices. More information on the CNSC and TC regulatory framework can be found on the CNSC's website. Together, these processes ensure that transportation is comprehensively regulated, with the Impact Assessment addressing Project-site effects and the CNSC transportation package certification and transport licensing processes addressing the safety and regulation of used fuel transportation along the broader transportation corridor. The philosophy behind the transportation of radioactive materials, including used fuel, is that safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents. The packaging itself provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Given the robust design and testing requirements for transportation packages, transportation accidents involving used nuclear fuel are expected to be conventional in nature, such as traffic collisions, with no release of radioactive material. Each package provides the same level of safety and is subject to the same level of control and oversight, which is independent of the number of shipments conducted annually. The transportation of used nuclear fuel is a well-established and highly regulated activity in Canada and internationally. Used fuel is a solid material that cannot spill. Additionally, it will be transported in a certified package that is designed and tested to protect the public and the environment under both normal operating conditions and severe accident conditions. The test conditions described in the safety standards are used to demonstrate that a package can provide adequate radiation shielding and containment of radioactive materials under normal conditions of transport and the conditions expected in a severe accident. The packages must be designed to withstand a drop test, puncture test, fire test and immersion test to simulate cumulative accident scenarios, including immersion in water. Please refer to the Preliminary Transportation Plan (Appendix G) for more information. An important tool in addressing the safety of used fuel shipments is the use of accident reconstructions to predict the performance of used fuel packages and transport systems under severe real-world accident conditions. The NWMO reviewed and analyzed real-world accident reconstructions. In all scenarios, had these accidents involved used fuel transportation packages, the packages would have survived the accidents and met regulatory requirements for

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			containment and dose rate limits, demonstrating the robustness of the regulatory framework For more information about transportation packages used to transport used nuclear fuel, please see our Confidence in Transportation Package Performance report (Appendix D). Even in the extremely unlikely and non-credible scenario that a transportation package were breached, any release of radioactive material would be expected to be limited, and widespread contamination would be very unlikely. In any transportation accident, procedures set out in the approved Emergency Response Plan would be followed to protect public safety, manage the incident, and return the site to normal conditions. In 2012, the NWMO prepared an assessment that estimated radiological dose to members of the public resulting from the transport of used nuclear fuel in the Used Fuel Transportation Package (UFTP). The dose estimates were built around generic, internationally available exposure time, distance and frequency assumptions. In 2014, work was initiated to refine these assumptions and to frame them in a Canadian context. Carleton University was contracted by the NWMO to assess exposure times, distances and frequencies between the members of the public and a passing UFTP along a hypothetical transport route. The data collected by Carleton reflects a realistic, current Canadian perspective on the time, distance and frequency relationships between members of the public and a UFTP shipment. Radiological doses to members of the public were estimated to range between approximately 0.0000013 to 0.00054 mSv per year with certain roadway workers potentially receiving the highest dose. All doses were calculated to be orders of magnitude below the regulatory dose limit of 1 mSv per year for a member of the public. The member of the public receiving the highest annual dose was determined to be a traffic control person (roadside worker), who may receive an annual dose 1900 times less than the public dose limit or a dose equivalent to that received during 8 minutes of flight in a jet airplane. For workers, occupational doses were assessed to be within a range of approximately 0.012 to 0.35 mSv per year with members of the transport crew receiving the highest dose; approximately 1/3 of the public dose limit or equivalent to the dose received during 88½ hours of flight in a jet airplane. The transport crew would receive only about 15% of the dose a typical flight crew receives annually. For more information on doses from transportation of used fuel, please refer to the NWMO report: Assessing Radiological Dose to Members of the Public and Workers during UFTP Transportation (NWMO, 2015). Additionally, please refer to the Worker Dose Assessment (Appendix I) and the Public Dose Assessment (Appendix J). These studies remain valid for the NWMO's transportation of used fuel, which is not expected to commence until 2043, since the Preliminary Transportation Plan (Appendix G) and applicable regulations remains substantially the same as it was at the time that the studies were completed.

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CNSC-26	Transportation (Table 4.1 and Section 1.7)	The IPD references lessons learned from international used fuel management organizations in Sweden and Finland who have transport regulations in place which are similar to Canada. The NWMO should provide additional details on the international benchmarking conducted for how transport was considered in those projects and how it compares to the proposed project.	All industrialized countries, including Canada, Sweden and Finland, use the International Atomic Energy Agency (IAEA) SSR-6, <i>Regulations for the Safe Transport of Radioactive Material</i> as the basis to regulate the packaging and transport of radioactive material, including radioactive waste. These regulations were first published in 1961 and have been revised regularly to keep pace with scientific and technological developments. The philosophy behind the transportation of radioactive materials, including used fuel, is that safety is inherent to the package design and the robustness of the packaging corresponds to the hazard level of the contents - the more hazardous the material the tougher the package. The packaging itself provides protection against radiation and prevents leakage, even in the event of accidents, minimizing the need for special handling or administrative controls. Package designs are combined with additional regulatory controls including labeling, placarding, quality assurance and maintenance records, and allow for radioactive material to be carried safely in all modes of transport. The package has to provide shielding to protect workers, the public and the environment against the effects of radiation under both normal and accident conditions of transport. As a result, in over 60 years there has never been a transport incident that has caused a significant radiological hazard to people or the environment. Specifically speaking to the transportation of used fuel, Sweden safely transports over 80 large casks of spent nuclear fuel annually from coastal nuclear power plants to the country's central interim storage facility via sea, primarily using a vessel designed for the transportation of used fuel. Approximately 250 shipments of irradiated (used) nuclear fuel are safely transported annually in France, using a combination of road and rail transport. In the United States, approximately 25 to 100 shipments of spent nuclear fuel occur annually and over the last 55 years, over 2,500 cask shipments have occurred with no radiological releases to the environment or harm to the public. These countries have enacted regulations based on the requirements established by the IAEA transport regulations and use transport packages that are designed to the same requirements to the ones that are used in Canada.
CNSC-27	Waste (Table 23.1)	Table 23.1 in the IPD provides a broad overview of the wastes (conventional, hazardous, radioactive) that will be generated at the different licensing stages. The level of detail is sufficient for the IPD; however, as per the <i>General Nuclear Safety and Control Regulations</i> , the name, quantity, form, origin, and volume of any radioactive waste or hazardous waste that may result from the activity to be licensed, including waste that may be stored, managed, processed, or disposed of at the site of the activity to be licensed, and the proposed method for managing and disposing of that waste, will be required for the activities that will be encompassed at the first licensing stage. This should be considered in the IS.	The NWMO recognizes the <i>General Nuclear Safety and Control Regulations</i>, specifically section 3(1)(j), with respect to identifying the characteristics of radioactive or hazardous waste that may result from the activity to be licensed. The required information related to any hazardous waste resulting from the Initial Licence activities will be included in the Integrated Impact Statement and Initial Licence Application.

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CNSC-29	Canadian Codes and Standards	Though Section 18.5 in the IPD indicates that some structures will be governed by <i>CSA N291</i> , the NWMO is requested to provide an exhaustive list of civil structures for the project, and to specify which civil structures will comply with NBCC requirements and which structures will comply with <i>CSA N291</i> requirements in the IS.	No structures included in the scope of the Initial Licence are expected to contain nuclear materials or nuclear safety systems, and therefore <i>CSA N291</i> is not expected to apply during this phase. National Building Code of Canada (NBCC) requirements are likely to apply to structures erected during the Initial Licence activities. The applicability of <i>CSA N291</i> will be evaluated for specific structures, systems, and components inside the facilities that are expected to contain radioactive materials, e.g., the Used Fuel Packaging Plant. A complete list of civil structures will be included in the Integrated Impact Statement and Initial Licence Application. This list will identify if structures, systems and components within a facility are significant to nuclear safety and if so, expected to be designed, in a graded approach, to <i>CSA N291</i> requirements.
CNSC-30	Effects of the Environment on the Project	CNSC staff were unable to find any information in the IPD on the site's susceptibility to natural phenomena such as seismic events, tornadoes, and flooding. - For seismic design of the overall facility, it is CNSC staff expectation that the return periods selected for the design must reflect the nuclear waste repository context. The return periods typically considered in the NBCC (2 475 years, or a probability of exceedance of 2% in 50 years), or <i>CSA N289</i> series (10 000 years, or a probability of exceedance of 0.01% per year), may not be sufficient for the proposed project. To guarantee that load factors used for earthquake loading in codes and standards are appropriate, the return period of earthquakes in codes and standards are several orders of magnitudes higher than the lifespan of the facility. Because of the long-lived nuclear waste and the associated long lifespan of the proposed project the return period considered for the overall design should be established accordingly and thoroughly justified. The NWMO is requested to provide more information on this matter in the IS. For natural phenomena other than seismic, the NWMO is requested to provide more information on the strategy to address these matters and demonstrate the design of the facility will be adequate from a safety perspective in the IS.	The NWMO recognizes that the DGR facility will operate over a very long timeline, and thus the seismic design must be commensurate with the risks posed by this timeline. However, most surface facilities, including those that handle or store radioactive materials, are expected to have a service life of ~50 years. The use of National Building Code of Canada (NBCC) or <i>CSA N289</i> for seismic design will be dependent on the function and safety significance of each structure, system and component with respect to handling radioactive materials. The application of <i>CSA N289</i>, as applicable, will be performed in a graded approach. External events on the Project--such as natural phenomena including seismic events, tornadoes, and flooding--are considered as part of the pre-closure safety analysis, in accordance with REGDOC-2.4.4. These events are identified during the hazard identification process, where the frequency and potential failure modes are evaluated. The Pre-Closure Safety Analysis is expected to assess the overall risk of these events, which helps to inform or confirm the design requirements of the facilities and structures. The Integrated Impact Statement and Initial Licence Application will provide more information on the strategy to address natural phenomena on the Project, and how the design and safety of the facility are demonstrated.
CNSC-31	Sealing System	In Section 9.6.1 of the IPD, the operations activities and physical works planned for the project are presented. It is mentioned that, once a placement room is filled, it would be sealed from the main tunnel by a special seal made of two parts: one uses bentonite to stop water from getting through and the other uses a concrete barrier to hold everything in place, making sure that everything stays securely sealed. CNSC staff were unable to find any information on the design of the concrete part of the sealing system described in the IPD. The NWMO is requested to provide more information on this matter in the IS and to provide CNSC staff with the	Additional description of the underground emplacement rooms and the planned sealing system will be included in the Integrated Impact Statement and Initial Licence Application, commensurate with the level of design detail available at the time of publication. The underground repository will not be constructed as part of the Initial Licence, and therefore final detailed designs/specifications/drawings may not be available. The role of the concrete in the room seal is to mechanically constrain the bentonite buffer in the placement room during the operations and in the extended monitoring period until the buffer swelling pressure is counteracted by the access tunnel seals' emplacement during the decommissioning and closure phase.

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
		documents/reports/specifications/drawings in which the details are/will be elaborated, once available. The NWMO is also requested to explain how the concrete will be considered/modelled into NWMO analyses and how its impact on the environment (e.g., groundwater and surface water, fauna and flora, release of contaminants, etc.) will holistically be evaluated for the entire life of the facility.	The NWMO recognizes that the presence of concrete seals need to be considered in the long-term evolution of the underground repository. For example, degradation of the concrete rooms seals over time, the potential for degraded concrete seals to create areas of enhanced permeability within the repository, as well as the potential interaction of the concrete room seal with groundwater and subsequent impacts of the altered groundwater chemistry on the performance of other engineered barriers such as the buffer. Safety-relevant aspects of the long-term evolution of the repository including the performance of the concrete room seals are considered in the Post-Closure Safety Assessment, which is being developed in accordance with REGDOC-2.11.1 Volume III. Uncertainties related to the long-term performance of the concrete are a consideration in the formulation of scenarios and sensitivity cases to be considered in the Post-Closure Safety Assessment. Although the concrete itself is not expected to interact with the surface environment directly and therefore is expected to have no environmental impact, the Post-Closure Safety Assessment considers the impact of the concrete on contaminant transport, and therefore its indirect impacts on the environment (e.g., groundwater and surface water, fauna and flora).
CNSC-32	Cementitious-Based Materials	In the IPD, CNSC staff were unable to identify any information related to the details of the use of the several different types of cementitious-based materials (grout, concrete, etc.), as well as of the justification of their very long-term behavior in a nuclear waste management context. The NWMO is requested to provide more information on this matter in the IS and to provide the documents/reports/specifications/drawings in which the details are/will be elaborated, once available	Cementitious-based materials are included in the repository design, primarily in the sealing system and potentially in the structure of the placement room. These materials are primarily included to provide structural support and physical separation, isolating the used fuel containers in the emplacement rooms from the access tunnels. The primary barrier containing the fuel is the used fuel container (UFC). The UFC is a purpose-built container, designed for the mechanical stresses and loads expected to be present at repository depth. The UFC is coated in a layer of corrosion-resistant copper. The UFCs are surrounded by compacted bentonite, which acts as a hydraulic barrier, mitigating the transport of water. While concrete is present in the emplacement room seal, it is not credited as a significant barrier of contaminant transport. As discussed in the response to CNSC-31, the presence of cementitious-based materials is a known aspect to the long-term contaminant transport modelling, and will be further discussed and assessed in the Post-Closure Safety Assessment developed in accordance with REGDOC-2.11.1 Volume III. The NWMO recognizes the importance of the characteristics of the barrier systems, including cementitious-based materials, and will provide more information in the Integrated Impact Statement and Initial Licence Application, commensurate with the level of design detail available at the time of publication. The underground repository will not be constructed as part of the Initial Licence, and therefore final detailed designs/specifications/drawings may not be available.

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
CNSC-33	Quality Management	In the IPD, CNSC staff were unable to identify specific information related to the Quality Management System (Quality Control, or QC, and Quality Assurance, or QA) for design, engineering and construction activities related to civil works and civil structures. In particular, it would be expected that QC and QA activities would be performed separately and in a fully independent fashion. The NWMO is requested to explain the process it intends to implement with regards to QA/QC for design, engineering and construction activities related to civil works and civil structures in the IS, and to provide CNSC staff with the documentation in which these are documented, once available.	The NWMO operates under a Management System suite of programs, including the Conduct of Engineering, Safety Assessment, and Site Characterization programs, which incorporate nuclear industry best practices for quality management. In addition, a separate Quality Assurance Program is in place to provide oversight. As the NWMO transitions into its Integrated Project Delivery model, and in preparation of becoming a nuclear licensee, these programs are in the process of being revised to ensure consistency with the requirements of CSA N286 <i>Management system requirements for nuclear facilities</i>. The NWMO will explain the quality control and quality assurance programs and processes as they apply to the works and activities to the Project, with a focus on those works and activities included in the scope of the Initial Licence, in the Impact Statement and Initial Licence Application. The full suite of Management System program documents, including those related to QC and QA will be submitted to the CNSC as a part of the Integrated Impact Statement and Initial Licence Application.
CNSC-34	Climate Change	It is unclear how the effects of climate change will be incorporated into the design of the proposed project, including incorporating its effects on the proposed project's fitness for service from a long-term perspective. The NWMO is requested to provide more information on this matter in the IS.	The NWMO recognizes the importance of climate change, especially on the overall design, and also the potential effects on the Project's fitness for service program and requirements. The effects of climate change on the Project are currently being evaluated. Results of these assessments, and discussions on how climate change is being considered in the design of the Project, will be included in the Integrated Impact Statement and Initial Licence Application.
CNSC-35	Contingency Plans	In Section 9.1 of the IPD, it is mentioned that " <i>Once operations are complete, there would be an approximate 100-year phase of extended monitoring, decommissioning and closure under CNSC licence. During this 100-year period, the DGR would be monitored for several decades to confirm that the natural and design features are performing as expected and containing the radioactivity of used fuel bundles</i> ". It is unclear what contingency plans are being / will be developed should it be found that natural and design features don't perform as expected. The NWMO is requested to provide more information on this matter in the IS.	The host rock formation, combined with the engineered barriers of the used fuel container and bentonite buffer, are expected to be able to isolate the used fuel from the surface environment for at least a million years. The evolution of the facility with time, and the potential for contaminant transport from the facility into the surface environment is evaluated in the Post-Closure Safety Assessment, developed in accordance with REGDOC-2.11.1 Volume III. The Post-Closure Safety Assessment includes scenarios where natural and designed features don't perform as expected, and confirms that the results remain within acceptance criteria. If, during the extended monitoring period, it is found that the natural and designed features are not performing as expected, mitigative actions can be taken, including the development of additional barriers. Furthermore, while there is no intent of retrieving the waste from the DGR facility, it is designed in such a way that waste retrieval should remain technically feasible post-closure under exceptional circumstances. More discussion on this topic will be included in the Integrated Impact Statement and Initial Licence Application.

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
CNSC-36	Description of the Project	In general, the IPD only identifies used CANDU fuel to be placed in the DGR. However, <i>Chapter 12 - Services provided to other owners of nuclear fuel waste</i> indicates that used fuel from AECL including used fuel from Canadian research reactors in tables 12-1 and 12-2 would also be part of the DGR inventory. Reference to the 2024 Fuel projection report is also made which also mentions other fuel types than CANDU Fuel. The NWMO is requested to provide the specific information on all used fuel to be placed in the DGR in the IS.	The NWMO is responsible for the long-term management of all used nuclear fuel generated in Canada. The vast majority of the fuel inventory is made up of CANDU fuel bundles resulting from decades of operations of CANDU reactors across Canada. A small portion of this used fuel belongs to AECL, as a result of prototype and research reactor operations. Most of AECL's used fuels are prototype CANDU bundles, while the remaining fuels were used in reactor fuel research, medical radioisotope production and for general radiation and nuclear physics research applications. While the NWMO is responsible for the eventual management all of Canada's nuclear fuel, it is not necessarily required that all fuel be included in this particular Project now undergoing impact assessment. The IPD refers to a capacity of 5.9 million used fuel bundles, but is generally non-specific about CANDU fuel bundles in the body of the submission. The "Chapter 12" referenced in the comment is from <i>Choosing a Way Forward</i>, a 2005 report which was appended to the IPD to give additional context to the public on the history, purpose, and conceptual plans of the NWMO. The final inventory of fuel into the DGR will be a function of at least the following studies and agreements: - The Waste Acceptance Criteria, and the used fuel owner's ability to meet the Waste Acceptance Criteria. - The results of the Safety Case, with important inputs from the Pre-Closure Safety Analysis and Post-Closure Safety Assessment. - The hosting agreements between NWMO and Wabigoon Lake Ojibway Nation, and the Municipality of Ignace, respectively. - Any additional constraints or conditions imposed by an authority having jurisdiction over the project, i.e., the CNSC. Specific information about the estimates for used fuel to be placed into the DGR will be included in the Integrated Impact Statement and Initial Licence Application.
CNSC-37	Nature of Hazard	Appendix 3 describes the hazards associated with used CANDU fuel; however, there is no description of the hazards associated with other types of used fuel to be placed in the DGR. The NWMO is requested to provide detailed information on this matter in the IS.	It is understood that the "Appendix 3" referred to in the comment is referencing "Appendix 3 / Nature of the Hazard", which is an appendix to <i>Choosing a Way Forward</i>, a 2005 report which was appended to the IPD to give additional context to the public on the history, purpose, and conceptual plans of the NWMO. Consistent with the response to CNSC-36, the Integrated Impact Statement and Initial Licence Application will provide more specific information about the estimates for used fuel to be placed into the DGR, and their relative hazards.

Response Identifier	Topic/Section	Comment/Advice	NWMO Response
CNSC-38	Status of Used Nuclear Fuel in Canada (Appendix 4)	The projected inventory only describes the total inventory of 5.9 million used fuel bundles from the current fleet of reactors to end of life, as outlined in the NWMO's 2024 Nuclear Fuel Waste Projections Report (NWMO, 2024). The NWMO is requested to provide the projected inventory of all used types to be placed in the DGR in the IS.	It is understood that the "Appendix 4" referred to in the comment is referencing "Appendix 4 / Status of Used Nuclear Fuel in Canada", which is an appendix to <i>Choosing a Way Forward</i>, a 2005 report which was appended to the IPD to give additional context to the public on the history, purpose, and conceptual plans of the NWMO. The Project is planning for a total of 5.9 million used fuel bundles. Consistent with the response to CNSC-36, the Integrated Impact Statement and Initial Licence Application will provide more specific information about the estimates for used fuel to be placed into the DGR.
CNSC-39	Description of the Project	The terms long term storage and disposal are used interchangeably. The website refers to the project as long term storage and isolation of the Used Fuel, but the IPD mentions long term storage, isolation, management and disposal. REGDOC 3.6 defines long term management as "The long-term management of radioactive nuclear waste by means of storage or disposal" from a regulatory standpoint we will need to be clear on if the project is for the storage or disposal of used fuel. The NWMO is requested to provide more information on this matter in the IS.	It is recognized that the NWMO uses "long-term management" and "disposal" interchangeably in the IPD. From a regulatory perspective, the DGR project is intended to meet the requirements of a disposal facility. The DGR is being designed as a permanent solution for the used fuel, not reliant on active human controls for long-term safety, and with no intention of retrieving the waste material. However, waste retrieval should remain technically feasible post-closure under exceptional circumstances. The Safety Case and the Post-Closure Safety Assessment are developed in accordance with REGDOC-2.11.1 Volume III, and are intended to satisfy CNSC requirements for the disposal of fuel waste in Canada. More clarification on the difference between long-term storage/management and disposal will be included in the Integrated Impact Statement and Initial Licence Application.

Appendix C – Ignace Hosting Agreement

HOSTING AGREEMENT

between

NUCLEAR WASTE MANAGEMENT ORGANIZATION

and

THE CORPORATION OF THE TOWNSHIP OF IGNACE

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HOSTING AGREEMENT

THIS HOSTING AGREEMENT is dated as of March 18, 2024 (the “**Effective Date**”),

BETWEEN:

NUCLEAR WASTE MANAGEMENT ORGANIZATION,
a not-for-profit corporation existing under the laws of Canada
(“**NWMO**”)

and

THE CORPORATION OF THE TOWNSHIP OF IGNACE,
a corporation existing under the laws of Ontario
(the “**Municipality**”)

WHEREAS:

- A. In 2002, Parliament passed the *Nuclear Fuel Waste Act* (Canada) (“**NFWA**”), requiring the owners of used nuclear fuel in Canada to establish a waste management organization as a separate legal entity to propose and implement an approach for the management of used nuclear fuel. In accordance with the NFWA, NWMO was established by Canada’s nuclear electricity producers and assumed responsibility for designing and implementing Canada’s plan for the safe, long-term management of used nuclear fuel.
- B. In 2007, the Government of Canada selected Adaptive Phased Management as Canada’s plan for the long-term management of used nuclear fuel. APM calls for the centralized containment and isolation of Canada’s used nuclear fuel in a deep geological repository with an informed and willing host.
- C. In 2010, NWMO initiated a process to select a site for the Project, and 22 communities (including the Municipality) proactively expressed an interest by the end of 2012. Since then, NWMO has been engaged in a multi-year, community-driven process to identify a site where Canada’s used nuclear fuel can be safely contained.
- D. In 2020, NWMO announced that it had narrowed down the potential host site to two, including: (i) the WLON-Ignace area, which includes the Project Area; and (ii) the Saugeen Ojibway Nation-South Bruce area.
- E. The Municipality has completed the Community Studies and developed the Community Principles, as informed by the Community Pillars, which have aided the Parties in the negotiation of this Agreement.
- F. The Municipality is currently in the process of undertaking its Willingness Process which has been informed by the Community Vision and is reflective of the values, beliefs and

principles held by both the Municipality and NWMO through engagement, dialogue and mutual learning.

- G. Ignace Council has passed a resolution, dated as of the Effective Date and attached hereto as Schedule G, setting out the Municipality's commitment to the development of a strategic capacity plan designed to increase its capability and capacity to successfully undertake the obligations set out in this Agreement (the "**Capacity and Capability Commitment**").
- H. NWMO supports the objectives set by the Municipality in the Capacity and Capability Commitment.
- I. The Parties agree that the purposes of this Agreement include:
 - i. fostering and facilitating effective communication between the Parties through the sharing of relevant information, on a regular and ongoing basis, during the Term;
 - ii. developing and maintaining a strong working relationship between the Parties throughout the Term;
 - iii. aligning the interests of the Parties in respect of the Project;
 - iv. setting out the process and manner by which willingness and support for the Project by the Municipality shall be evidenced prior to the Commencement Date;
 - v. evidencing the Municipality's agreement to be a Willing Host, if that is the outcome of the Municipality's Willingness Process and the Project Area is selected as the site for the Project;
 - vi. describing the Project, including NWMO's process for advancing the Project design in accordance with Applicable Laws and the Regulatory Approvals; and
 - vii. establishing a framework for the Municipality's participation in the Regulatory Approvals processes for the Project, as set out in Article 5, if the Project Area is selected as the site for the Project.
- J. The Parties wish to enter into this Agreement: (i) to set out the benefits to, and obligations and rights of, each Party in respect of the Project in the event that the Project Area is or is not selected as the site for the Project; (ii) to ensure that adequate provision is made for the inherent adaptability of the APM process and the long-term nature of the Project; and (iii) to set out the respective roles and responsibilities of the Parties with respect to the Regulatory Processes applicable to the Project.

NOW THEREFORE in consideration of the mutual covenants and agreements herein and other good and valuable consideration, the receipt and sufficiency of which are hereby acknowledged, the Parties agree as follows:

ARTICLE 1 DEFINITIONS

1.1 Defined Terms

As used in this Agreement, the following terms have the following meanings:

“Aboriginal Group” means any first nation recognized as a “band” within the meaning of the *Indian Act* (Canada), Métis group and/or other aboriginal group.

“Accepted Fuel Sources” has the meaning given in Section 2.2.1(a).

“Adaptive Phased Management” or **“APM”** means the approach selected by the Government of Canada for the long-term management of used nuclear fuel, which consists of both a technical method and a management system, and includes the following key attributes: (a) ultimate centralized containment and isolation of Canada’s used nuclear fuel in a deep geological repository; (b) phased and adaptive decision-making; (c) continuous monitoring; (d) retrievability; and (e) citizen engagement.

“Agreement” means this Hosting Agreement, including the recitals, and all schedules attached to hereto, in each case as they may be amended or supplemented from time to time.

“AIA” has the meaning given in Section 15.4.4.

“Annual Fuel Projection Report” means NWMO’s annual report titled “Nuclear Fuel Waste Projections in Canada” which, among other things, includes: (a) a summary of the existing inventory of used nuclear fuel waste in Canada; and (b) the location of such used nuclear fuel waste. The Annual Fuel Projection Report is updated annually and made publicly available on NWMO’s website ([Link to the most recent Nuclear Fuel Waste Projections in Canada Report available as of the Effective Date](#)).

“Annual Payment” has the meaning given in Section 2.1 of Schedule B.

“Annual Work Plan” has the meaning given in Section 5.1 of Schedule D.

“Anticipated Schedule” has the meaning given in Section 2.3.1.

“Applicable Law” means all laws, ordinances, regulations, by-laws, Authority Requirements, judgments and decrees, injunctions, writs and orders of any Governmental Authority and the terms and conditions of any Regulatory Approvals that apply to either Party, the Project, or the terms of this Agreement.

“Arbitration Rules” has the meaning given in Section 17.1.7(b).

“Authority Requirements” means any legally enforceable order, direction, directive, policy, standard, guideline or rule of or by any Governmental Authority, including legally enforceable IA Agency and CNSC policies, regulatory documents, administrative interpretations, directives and staff review procedures.

“Base Project Scope” has the meaning given in Section 2.2.1.

“Benefits Payment” has the meaning given in Section 2.1(b) of Schedule B.

“Bundles” means bundles of nuclear fuel waste in Canada, as reported in the then-current Annual Fuel Projection Report.

“Business Days” means any day other than Saturday, Sunday or any day on which the offices of the Government of Ontario or banking institutions in Thunder Bay, Ontario are not open for business.

“Capacity and Capability Commitment” has the meaning given in the recitals.

“Centre of Expertise” has the meaning given in Section 1.1 of Schedule C.

“CNSC” means the Canadian Nuclear Safety Commission established pursuant to the NSCA and includes any successor thereof.

“Commencement Date” means the date that NWMO delivers the NWMO Site Selection Notice to the Municipality.

“Committed Costs” means the amount of funding, as evidenced by project budgets, invoices and any other documentation reasonably requested by NWMO, that the Municipality requires to complete any capital project funded using the Financial Benefits where physical work of a significant nature has commenced as of the applicable date. For further clarity, physical work of a significant nature is work that is integral to the construction of such capital project. Preliminary activities, such as environmental or geological assessments, or initial preparatory work (including, for example, site clearing, fence construction or development of access roads), shall not be considered integral to such capital project.

“Communications Protocol” means the communications protocol developed and agreed by the Parties as of the Effective Date and attached hereto as Schedule F, as it may be amended from time to time by the Parties in accordance with Section 2.1(h) of Schedule D and the terms of the Communications Protocol.

“Community Decision” means a clear statement delivered to NWMO from the Municipality, in accordance with Section 21.1, as evidenced by an Ignace Council resolution, that the Municipality is or is not a Willing Host.

“Community Pillars” means the community pillars of the Municipality, which are community development, economic development, tourism development and effective marketing and communications.

“Community Principles” means the following priorities and objectives developed by the Municipality to foster and advance community well-being:

- (a) People: To promote community growth that celebrates a “small-town” rural sense of place that embraces both current and new residents with varying backgrounds,

cultures, peoples, and age groups. Part of the promotion of community growth will be the establishment of a tourism strategy and the establishment of youth training programs which could include bursaries.

- (b) Economics and Finance: To sustain and complement local businesses while supporting growth in mixed development opportunities for the local and regional economies, as well as maximizing local opportunities for training, skills development, and Project employment.
- (c) Infrastructure: To coordinate planned and integrated infrastructure and services that support both the Municipality and NWMO by enhancing, complementing, and investing in new and present community facilities/developments.
- (d) Community and Culture: To appreciate and celebrate the Municipality's "small-town" charm, heritage, and culture whereby the Project is now a chapter of the Municipality's ongoing story.
- (e) Natural Environment: To be mindful of the Municipality and NWMO's strong connection to the outdoors and natural resources, being environmental stewards who protect and enhance the local and surrounding area, as well as support a variety of economic and recreation activities.

"Community Studies" means the studies undertaken by the Municipality in respect of the Project, including the studies entitled: (a) Growing the Population and Opportunities (Population Growth); (b) Workforce Development Program; (c) Local and Regional Youth Economic Development; (d) Community Health & Protection; (e) Community Identity & Resiliency; (f) Connection with Natural Environment; (g) Recreation & Social Services; (h) Labour Baseline; (i) Labour - Opportunities to Enhance Local Employment; (j) Housing; (k) Municipal Finance, Pre-Construction Economic Development, Construction and Operations Economic Development; (l) Traffic & Roads; (m) Emergency Services; (n) Recreation & Social Infrastructure; (o) Municipal Infrastructure, and (p) Tourism.

"Community Vision" means the Municipality's community vision developed by the Municipality leadership and staff, in collaboration with the Municipality's residents and NWMO, as set out in Ignace Council resolution #379/2020.

"Conceptual Design Report" means the Deep Geological Repository Conceptual Design Report Crystalline / Sedimentary Rock, APM-REP-00440-0211-R000 published by NWMO in September, 2021, which is posted on NWMO's website ([Link to Conceptual Design Report](#)).

"Confidential Information" has the meaning given in Section 15.1.1.

"Construction Phase" means the period of time described in the Anticipated Schedule, commencing on January 1st of the year following the issuance of the Licence to Construct.

"Contractor" means, in respect of a Party, a Person (including that Person's successors and permitted assigns) engaged by such Party, or any subcontractor at any tier of such Party, in respect of the Project.

“**CPI**” means the Consumer Price Index for Canada, All Items (Not Seasonally Adjusted) as published by Statistics Canada, provided in each case that if CPI ceases to be published by Statistics Canada there shall be substituted an available replacement index that most nearly, of those then publicly available, approximates the intent and purpose of the CPI that has so ceased or changed, and this Agreement shall be amended as necessary to accommodate such replacement index, all as determined by written agreement of the Parties or failing agreement, in accordance with Article 17.

“**CPI Adjustment**” means the quotient obtained by dividing: (a) CPI for the month of November in that calendar year; by (b) CPI for the month of November, 2025.

“**Delay Period**” has the meaning given in Section 11.2.3.

“**Detailed Financial Benefits Table**” has the meaning given in the preamble of Schedule B.

“**DGR**” means the nuclear waste deep geological repository to be located within the Project Area, if the Project Area is selected as the site for the Project.

“**Disclosing Party**” has the meaning given in Section 15.1.1.

“**Discretionary Benefit**” has the meaning given in Section 5.1 of Schedule B.

“**Dispute**” has the meaning given in Section 17.1.1.

“**Dispute Notice**” has the meaning given in Section 17.1.1.

“**Effective Date**” has the meaning given in the Preamble.

“**Emergency Services Base**” has the meaning given in Section 4.1 of Schedule C.

“**Emplacement Fee**” has the meaning given in Section 3.1 of Schedule B.

“**Exit Benefits**” means the Municipality Exit Benefits or NWMO Exit Benefits, as applicable.

“**Exit Event**” means a Municipality Exit Event or an NWMO Exit Event, as applicable.

“**Extended Monitoring Phase**” means the period of time described in the Anticipated Schedule, commencing on January 1st of the year following the delivery by NWMO of the Permanent Cessation Notice, during which the long-term safety and performance of the DGR will be monitored.

“**Facility**” means:

- (a) the DGR;
- (b) all other buildings, facilities, equipment, structures and components located within the Project Area;

- (c) all surfaces, services, utilities, roadways and parking spaces required to support such buildings, facilities, equipment, structures and components, or to operate, maintain and repair, decommission, close and monitor the DGR and related facilities located within the Project Area; and
- (d) all other supporting systems, infrastructure and improvements within the Project Area.

“Financial Benefits” has the meaning given in Section 11.1.1.

“Governmental Authority” means any federal, provincial, local, or municipal government, governmental department, commission, board, bureau or agency, or any judicial, regulatory or administrative body, each having jurisdiction as to the matter in question.

“Housing and Infrastructure Plan” has the meaning given in Section 3.1 of Schedule C.

“Housing Study” has the meaning given in Section 3.1 of Schedule C.

“IA Agency” means the Impact Assessment Agency of Canada established pursuant to the IAA and includes any successor thereof.

“IA Process” means the integrated impact assessment process with respect to the Project undertaken pursuant to the IAA.

“IAA” means the *Impact Assessment Act* (Canada).

“Ignace Council” means the council for the Municipality, as elected in accordance with the *Municipal Act, 2001* (Ontario).

“Implementation Committee” has the meaning given in Section 10.1.1.

“Indigenous Knowledge” means Indigenous traditional knowledge, including knowledge of the natural environment and traditional lands, and cultural and spiritual values that members of the community may wish to share to preserve, communicate and contextualize their relationships with culture and landscape that have been locally developed over time. Indigenous Knowledge is: (a) an evolving, complex and sophisticated system of knowledge drawing on millennia of wisdom and experience; (b) an evolving knowledge system that ranges in diversity from governance, ecology, biology, ecosystems, harvesting, science and other aspects; and (c) such knowledge is held by the respective knowledge holders and their communities.

“Indigenous Knowledge Policy” means NWMO’s Indigenous Knowledge Policy dated July 2020, which is posted on NWMO’s website ([Link to Indigenous Knowledge Policy](#)), as may be amended, modified, supplemented, or replaced from time to time.

“Inquiry” has the meaning given in Section 14.2.1.

“Interruption of Operations” has the meaning given in Section 11.4.1.

“KDSB” has the meaning given in Section 13.1.1(b).

“Learn More Centre” means the lands with property identification numbers of 42103-0173 and 42103-0171 and municipally known as 304 Main Street, Ignace, Ontario, together with all buildings, structures, appurtenances and improvements situated thereon.

“LET Program” has the meaning given in Section 9.1.2.

“Licence to Construct” means the licence to construct in respect of the Project issued to NWMO by the CNSC pursuant to the NSCA.

“Licence to Operate” means the licence to operate in respect of the Project issued to NWMO by the CNSC pursuant to the NSCA.

“Licence to Prepare Site” means the licence to prepare site in respect of the Project issued to NWMO by the CNSC pursuant to the NSCA.

“Licensing Phase” means the period of time described in the Anticipated Schedule, commencing on January 1st of the year following a site selection decision being made by NWMO.

“LMC Option” has the meaning given in Section 19.6.1.

“Local Business” has the meaning given in the Procurement Policy.

“Local Emergency Service” has the meaning given in Section 13.1.1(b).

“Local Indigenous Communities” means: (a) WLON; and (b) such other Indigenous communities that NWMO identifies from time to time.

“Losses” has the meaning given in Section 11.7.3(c).

“MAA” has the meaning given in Section 13.1.3.

“Major Applications” means: (a) the impact assessment of the Project under the IAA; and (b) any licence application made to the CNSC in respect of the Project, including the Licence to Prepare Site, Licence to Construct, and the Licence to Operate.

“MFIPPA” has the meaning given in Section 15.4.1.

“Milestone Event” has the meaning given in Section 1.1 of Schedule B.

“Milestone Payment” has the meaning given in Section 1.1 of Schedule B.

“Municipality” has the meaning given in the Preamble.

“Municipality Default” has the meaning given in Section 11.7.1.

“Municipality Exit Benefits” has the meaning given in Section 19.1.1.

“Municipality Exit Event” means that, following completion of its Willingness Process, the Municipality has delivered Notice to NWMO that the Municipality is not a Willing Host.

“NFWA” has the meaning given in the recitals.

“Notice” means any notice, demand, approval, consent, information, agreement, offer, request or other communication to be delivered in writing in accordance with Section 21.1.

“Notice of Default” has the meaning given in Section 11.7.1.

“NSCA” means the *Nuclear Safety and Control Act* (Canada).

“NWMO” has the meaning given in the Preamble.

“NWMO Exit Benefits” has the meaning given in Section 19.2.1.

“NWMO Exit Event” means the occurrence of all of the following events:

- (a) the Municipality has delivered a Notice to NWMO that, based upon the Community Decision, the Municipality is a Willing Host; and
- (b) prior to the Commencement Date, as a result of NWMO’s site selection decision for the Project or otherwise, NWMO delivers Notice to the Municipality that it is not proceeding with the development of the Project within the Project Area.

“NWMO Member” means any Person that is a member of NWMO in accordance with the NWFA.

“NWMO Site Selection Notice” means the Notice delivered by NWMO to the Municipality that the Project Area has been selected as the site for the Project.

“NWMO Termination Benefits” has the meaning given in Section 19.3.1.

“NWMO Termination Event” means, following the Commencement Date, NWMO has delivered Notice to the Municipality that it is abandoning development of the Project in the Project Area.

“Operating Payment” has the meaning given in Section 2.1(c) of Schedule B.

“Operations Phase” means the period of time described in the Anticipated Schedule commencing on January 1st of the year following the issuance of the Licence to Operate.

“Parties” means NWMO and the Municipality, and each being a **“Party”**.

“Permanent Cessation Notice” has the meaning given in Section 11.4.3.

“Person” means any natural person, corporation, company, firm, joint venture, unincorporated association or organization, union, partnership (general or limited), limited liability company, unlimited liability company, trust, trustee, executor, administrator or other legal representative, Governmental Authority, Aboriginal Group or any other entity or association.

“Personnel” means:

- (a) with respect to a Party, any individual employed by, engaged by or seconded to such Party or any Contractor of such Party, including any consultants, agents, personnel, augmented staff, labour and other employees of such Party or any such Contractor, in each case which are used or engaged by such Party or such Contractor in relation to the Project; and
- (b) with respect to a Person other than a Party, any individual employed by, engaged by or seconded to such Person, including any consultants, agents, personnel, augmented staff, labour and other employees of such Person, in each case which are used or engaged by such Person in relation to the Project.

“Phase” means any of the Licensing Phase, Site Preparation Phase, Construction Phase, Operations Phase or Extended Monitoring Phase.

“Privacy Legislation” has the meaning given in Section 15.4.3.

“Procurement Policy” means NWMO’s Local and Indigenous Procurement Guide dated November 3, 2023, as may be amended, modified, supplemented, or replaced from time to time.

“Project” means all Phases of the development, construction, operation and decommissioning of the Facility, including, site selection, permitting (including, for clarity, obtaining all required Regulatory Approvals), design, engineering, licensing support, procurement, development, construction, installation, testing, commissioning, operation, maintenance, repair, decommissioning, closure and extended monitoring of the Facility, and the related training, infrastructure and ancillary buildings, and the handling, unpackaging, packaging, encasing, any other preparation, in each case conducted within the Project Area or by NWMO and its Contractors, movement and other transport, shielding and monitoring of the used nuclear fuel and associated nuclear waste to be contained in the DGR.

“Project Application Materials” means the submissions to a Governmental Authority in connection with a Major Application set out in Section 1 of Schedule E.

“Project Area” has the meaning given in Section 2.1.

“Project Emergency Response Plan” has the meaning given in Section 13.1.1(a).

“Project Information Materials” means the materials set out in Section 3 of Schedule E.

“Project Scope Modification” and **“Project Scope Modifications”** have the meaning given in Section 6.1.1.

“Project Scope Modification Notice” has the meaning given in Section 6.2.1(a).

“Prudent Practices” means any of the practices, methods and activities which, in the exercise of skill, diligence, prudence, foresight and reasonable judgment by a prudent Person engaged in similar practices, methods or activities, in light of the facts known or which ought to have been

known by such prudent Person at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, expedition and Applicable Law. Prudent Practices are not intended to be limited to the optimal practices, methods or activities to the exclusion of all others, but rather are intended to delineate acceptable practices, methods, or acts generally accepted.

“Purchase and Sale Agreement” has the meaning given in Section 19.6.2(a).

“Receiving Party” has the meaning given in Section 15.1.1.

“Reconciliation Policy” means NWMO’s Reconciliation Policy dated October 2019, which is posted on NWMO’s website ([Link to Reconciliation Policy](#)), as may be updated from time to time.

“Regulatory Approvals” means any consent, authorization, registration, filing, notification, certificate, licence, permit, approval or exemption therefrom, by, from, to, or with a Governmental Authority (including, for clarity, the Municipality), in each case as required pursuant to Applicable Law to undertake any part of the Project and includes all amendments and all non-automatic extensions or renewals of same.

“Regulatory Process” means any Governmental Authority process or proceeding in connection with obtaining or maintaining a Regulatory Approval in respect of the Project.

“Representatives” means, in respect of a Party, that Party’s: (a) shareholders and members and, in the case of NWMO, NWMO Members (including such NWMO Members’ shareholders); (b) Contractors; (c) counsel, accountants, financial advisors, technical advisors and other advisors to that Party or any such shareholder, member, NWMO Member or Contractor; (d) directors, officers, and Personnel of such Party, or such Party’s shareholders or NWMO Members; and (e) in the case of the Municipality, its elected officials.

“Segregated Account” has the meaning given in Section 14.2.3.

“Site Preparation Phase” means the period of time described in the Anticipated Schedule commencing on January 1st of the year following the issuance of the Licence to Prepare Site.

“Support Payments” has the meaning given in Section 2.1(a) of Schedule B.

“T&E Working Group” has the meaning given in Section 9.1.2.

“Term” has the meaning given in Section 20.1.

“Transportation Hub” has the meaning given in Section 4.1 of Schedule C.

“Tribunal” has the meaning given in Section 14.2.1.

“Willing Host” means a community that is informed and willing to support, accept and host the Project.

“Willingness Process” means the process followed by the Municipality in order for it to make an informed decision on whether it consents to being a Willing Host for the Project if the Project Area is selected by NWMO as the site for the Project.

“WLON” means Wabigoon Lake Ojibway Nation.

“Working Group” has the meaning given in Section 6.1 of Schedule D.

1.2 Interpretation

1.2.1 In this Agreement:

- (a) the tables of contents, headings and references to them in this Agreement are for convenience of reference only, shall not constitute a part of this Agreement, shall not define, limit, enlarge, modify or explain the scope, meaning or intent of this Agreement or any of its provisions, and shall not be taken into consideration in the interpretation of, or affect the meaning of, this Agreement;
- (b) unless the context otherwise requires, wherever used herein the plural includes the singular, the singular includes the plural, and each of the masculine, feminine and neuter genders include all other genders;
- (c) the word “including” and “includes” shall not be deemed limited by the specific enumeration of items but shall, in all cases, be deemed to be without limitation and construed and interpreted to mean “includes, without limitation” and “including, without limitation”;
- (d) the words “herein”, “hereof”, “hereto”, “hereafter” and “hereunder” and other terms of like import shall refer to this Agreement as a whole and not to any particular section or subsection hereof;
- (e) “in its sole discretion” shall be deemed to be “in its sole and absolute discretion”;
- (f) “for clarity”, “for certainty”, “for greater clarity”, “for greater certainty” or similar expressions are used interchangeably and shall be deemed to be without limitation;
- (g) except where the context requires otherwise (irrespective of whether some, but not all, references in a Schedule specifically refer to that Schedule or to other portions of this Agreement), references to “Articles”, “Sections” and “Schedules” shall be to articles, sections and schedules hereof and “Articles” and “Sections” shall mean and include sections, subsections and paragraphs and are used interchangeably and are synonymous;

- (h) except where the context requires otherwise, references to specific Articles, Sections, Schedules and other divisions of this Agreement followed by a number are references to the whole of the Article, Section, Schedule or other division of this Agreement as applicable, bearing that number, including all subsidiary provisions containing that same number as a prefix;
 - (i) the words in this Agreement shall bear their natural meaning except where otherwise defined in this Agreement;
 - (j) the Schedules to this Agreement are an integral part of this Agreement and references to this Agreement shall include a reference to all Schedules hereto, as the same may be amended, modified, supplemented, or replaced from time to time; and
 - (k) all references in this Agreement to a Schedule shall be to a Schedule of this Agreement.
- 1.2.2 Unless otherwise specified, any reference to a statute includes and is a reference to such statute and to the regulations and rules made pursuant to it, with all amendments in force from time to time, and to any statutes, regulations and rules that may be passed which have the effect of amending, supplementing, superseding or replacing such statutes, regulations or rules.
- 1.2.3 References to “days” shall mean calendar days, unless the term “Business Days” is used, “weeks” shall mean calendar weeks, and “months” shall mean calendar months, in each case under the Gregorian calendar.
- 1.2.4 References to Persons shall include their successors and assigns. References to a public organization shall include their successors and assigns, and if a public organization ceases to exist or ceases to perform its functions without a successor or assign, references to such public organization shall be deemed to include a reference to any public organization or any organization or entity which has taken over either or both the functions and responsibilities of such public organization, including Ignace Council.
- 1.2.5 A reference in this Agreement to any right, power, obligation or responsibility of any Governmental Authority shall be deemed to be a reference to the Governmental Authority that, pursuant to Applicable Law, has such right, power, obligation or responsibility at the relevant time.
- 1.2.6 In construing this Agreement, the rule known as the *ejusdem generis* rule shall not apply nor shall any similar rule or approach apply to the construction of this Agreement and, accordingly, general words introduced or followed by the word “other” or “including” or “in particular” shall not be given a restrictive meaning because they are followed or preceded (as the case may be) by particular examples intended to fall within the meaning of the general words.

- 1.2.7 Where this Agreement states that an obligation shall be performed “no later than” or “within” or “by” a stipulated date or event which is a prescribed number of days after a stipulated date or event, the latest time for performance shall be 5:00 p.m. on the last day for performance of the obligation concerned, or, if that day is not a Business Day, 5:00 p.m. on the next Business Day.
- 1.2.8 Where this Agreement states that an obligation shall be performed “on” a stipulated date, the latest time for performance shall be 5:00 p.m. on that day, or, if that day is not a Business Day, 5:00 p.m. on the next Business Day.
- 1.2.9 Any reference to time of day or date means the local time or date in Ignace, Ontario, located in the North American Central Time Zone, unless otherwise specified.
- 1.2.10 Any reference to currency, “dollars” or “\$” is to Canadian currency and any amount advanced, paid or calculated is to be advanced, paid or calculated in Canadian currency unless another currency is expressly specified in this Agreement.
- 1.2.11 The rule of construction that ambiguities are to be resolved against drafting parties does not apply to the interpretation of this Agreement, and there is no presumption that any doubtful or ambiguous expression is to be resolved in favour of any Party.
- 1.2.12 Where in this Agreement a section uses the phrase “without limiting Section ■”, it shall be deemed to be “without limiting the generality of Section ■” and “without limiting Section ■ in any way”.

1.3 Schedules

The following schedules are attached to and incorporated in this Agreement by reference and deemed to be a part hereof:

Schedule A	—	Project Area
Schedule B	—	Financial Benefits
Schedule C	—	Additional Benefits
Schedule D	—	Implementation Committee
Schedule E	—	Regulatory Decision-Making Deliverables
Schedule F	—	Communications Protocol
Schedule G	—	Capability and Capacity Commitment

ARTICLE 2 PROJECT DESCRIPTION

2.1 Project Area

If the Municipality is selected as a host community for the Project, the Facility will be located in the general area shown in the oval-shaped area and described as the “Revell Site” in Schedule A (the “**Project Area**”).

2.2 Project Scope

2.2.1 NWMO may emplace in the DGR:

- (a) used nuclear fuel sourced from:
 - (i) previous, existing and refurbished CANDU reactors in Canada, including the refurbished Pickering B Generating Station;
 - (ii) all previous and current operations of Atomic Energy of Canada Limited (or any predecessor or successor thereto); and
 - (iii) small modular nuclear reactors that have filed a licence to construct application with the CNSC on or prior to the Effective Date,
- (collectively, the “**Accepted Fuel Sources**”); and
- (b) any low- and intermediate-level nuclear waste produced by operation of the Project that is not further reduced, reused or recycled, or sent to another licensed disposal facility at the end of the Operations Phase,

(collectively, the “**Base Project Scope**”).

2.2.2 As at the Effective Date, the conceptual design for the Facility is articulated in the Conceptual Design Report. The Municipality acknowledges that, consistent with the inherent adaptability of the APM process and the long-term nature of the Project, and the iterative process of engineering design, the design set out in the Conceptual Design Report will continue to be updated, and may be superseded, as new information becomes available as a result of on-going investigation of the Project Area and in connection with future licensing submissions.

2.2.3 NWMO acknowledges and agrees that the following will not be emplaced in the DGR: (a) liquid nuclear fuel waste; (b) nuclear waste originating from any country other than Canada; (c) used nuclear fuel not included in Section 2.2.1, unless the Parties have complied with the Project Scope Modification process set out in Section 6.2; (d) low- and intermediate-level nuclear waste not included in Section 2.2.1(b); or (e) non-fuel high-level waste.

- 2.2.4 The Municipality acknowledges and agrees that NWMO has the right to make Project Scope Modifications to the Base Project Scope in accordance with Article 6.

2.3 Project Timeline

- 2.3.1 As of the Effective Date, NWMO anticipates that, if the Project Area is selected as the site for the Project, the Phases will occur in accordance with the following schedule (the “**Anticipated Schedule**”):

Phase	Anticipated Schedule	Anticipated Duration
Licensing Phase	2025-2031	7 Years
Site Preparation Phase	2032-2035	4 Years
Construction Phase	2036-2042	7 Years
Operations Phase	2043-2104	62 Years
Extended Monitoring Phase	2105-2174	70 Years

- 2.3.2 Notwithstanding the foregoing, the Municipality acknowledges and agrees that: (a) the Anticipated Schedule is based on information available to NWMO as of the Effective Date and the start date, end date and duration of each Phase remain subject to change over the course of the Project and pursuant to the Adaptive Phased Management approach; and (b) any delay to, or interruption or extension of, the Anticipated Schedule shall be addressed in accordance with Sections 11.2 to 11.7, as applicable.
- 2.3.3 Upon determining, with reasonable certainty, that any Phase will extend beyond the duration stipulated in the Anticipated Schedule, NWMO agrees that it shall deliver Notice to the Municipality in respect of such Phase extension. For clarity, the Parties acknowledge and agree that NWMO shall be deemed to have complied with this Section 2.3.3 upon delivery of Notice in respect of a Delay Period or Interruption of Operations pursuant to Section 11.2 or 11.4, as applicable.

ARTICLE 3 PROJECT PERFORMANCE STANDARD

3.1 Project Performance Standard

Each Party acknowledges and agrees that it shall perform all of its obligations under, and observe all provisions of, this Agreement in accordance with Applicable Law, the Regulatory Approvals, and Prudent Practices.

ARTICLE 4 COMMUNITY SUPPORT AND WILLINGNESS

4.1 Community Decision and Willingness Process

The Municipality will make best efforts to complete its Willingness Process and provide NWMO with the result of its Community Decision by July 30, 2024.

4.2 Support for the Project

- 4.2.1 Upon completion of the Willingness Process, if, based upon the Community Decision, the Municipality has determined that it is a Willing Host, the Municipality shall promptly deliver Notice of such Community Decision to NWMO, attaching a copy of the resolution of Ignace Council which evidences the Municipality's willingness and consent to be a Willing Host.
- 4.2.2 Upon delivery of the Notice described in Section 4.2.1, the Municipality acknowledges, confirms and agrees that:
 - (a) it is a Willing Host and consents and agrees to host the Project;
 - (b) it supports the Project, including, for greater certainty, any Project Scope Modification made in compliance with Section 6.2;
 - (c) notwithstanding its right to participate in any applicable Regulatory Process as a member of the public, it will, at NWMO's request, participate in any applicable Regulatory Processes in accordance with and subject to Article 5; and
 - (d) it shall recognize and respect the Regulatory Approvals that have been, or may in the future be, granted to NWMO for the Project.
- 4.2.3 The Municipality agrees to fulfill all of its obligations set out in this Agreement and further agrees, subject to Article 14, undertaken by it in good faith, and its rights under this Agreement, that it shall:
 - (a) not obstruct or impede NWMO or any of its Representatives, any Governmental Authority, or any other Person, from continuing, unrestricted, and unobstructed access to the Project Area required in connection with the Project, including operating the Facility and/or the Centre of Expertise;
 - (b) not engage in any action that could frustrate, delay or interfere with, or stop NWMO from proceeding with the Project, including the construction and operation of the Facility and/or the Centre of Expertise, without lawful justification;

- (c) use commercially reasonable efforts to promptly, and in any event, within twenty (20) days of receipt thereof, execute any consent or acknowledgement related to or required to fulfil its obligations under this Agreement, as may be reasonably requested by any Governmental Authority;
 - (d) use best efforts to attend, at NWMO's reasonable request and expense, non-regulatory forums (including international forums) related to the Project, and support the Project at such forums;
 - (e) at NWMO's reasonable request, make, publish or communicate to any Person or in a public forum, its support of the Project in accordance with this Agreement; and
 - (f) not, at any time, make, publish or communicate to any Person or in any public forum, (i) any disparaging, false or misleading remarks, statements or representations concerning the Project or NWMO, or (ii) any statement indicating that the Municipality does not support the Project.
- 4.2.4 The Municipality acknowledges the Reconciliation Policy and Indigenous Knowledge Policy issued by NWMO and NWMO's commitment to reconciliation with Indigenous communities and incorporation of Indigenous Knowledge as part of its development of the Project. The Parties acknowledge the importance of reconciliation with Indigenous peoples and agree that they are committed to supporting reconciliation efforts with Indigenous communities, including the Local Indigenous Communities, that are grounded in learning, action and meaningful relationship.

ARTICLE 5

PARTICIPATION IN REGULATORY DECISION-MAKING

5.1 Advanced Review of Major Applications

- 5.1.1 NWMO will provide the Municipality with an electronic copy of draft Project Application Materials in advance of submitting such materials to the applicable Governmental Authority. For greater certainty, the obligation to provide the Municipality with a copy of any draft Project Application Materials shall not extend to:
- (a) any minor or administrative amendment to, or renewal of, a Major Application; or
 - (b) the provision of any documents incorporated or referenced in any draft or final Project Application Materials; provided that, in accordance with Applicable Law, the Municipality will have the opportunity to review such documents as part of the Regulatory Processes.

For greater certainty, NWMO's obligation to provide Project Application Materials to the Municipality shall be exclusive of any Indigenous Knowledge unless applicable consent has been obtained from the relevant knowledge-holder.

- 5.1.2 The Municipality agrees to review and provide any comments on the draft Project Application Materials to NWMO in an editable electronic format (e.g., Microsoft Word format), within forty-five (45) days of the date such Project Application Materials are received.
- 5.1.3 NWMO will make good faith efforts to address and incorporate any comments provided by the Municipality that conform to the requirements of Section 5.1.2 and, where changes are made to the final Project Application Materials, to provide a copy of the final Project Application Materials to the Municipality. Notwithstanding the foregoing, the Municipality acknowledges and agrees that NWMO has ultimate discretion with respect to whether and how to incorporate the Municipality's comments in the final Project Application Materials.
- 5.1.4 For any comments provided by the Municipality that NWMO does not incorporate into the Project Application Materials:
 - (a) NWMO shall provide the Municipality with the reasons why such comments were not incorporated; and
 - (b) notwithstanding its obligations in Section 4.2.3 and Section 5.1.2, the Municipality shall not be prohibited from raising those unincorporated comments in any Regulatory Process, provided that, in such circumstance, the Municipality will not: (i) take any actions other than raising the Municipality's comments for consideration by the applicable Governmental Authority; and (ii) commence a judicial review or other litigation in respect of the Municipality's comments that are not incorporated into the final Project Application Materials.
- 5.1.5 The Municipality acknowledges and agrees that if it does not provide comments on the draft Project Application Materials that conform to the requirements of Section 5.1.2, it shall not submit any such comments to, or raise any issues or concerns directly related to the Project Application Materials with the applicable Governmental Authority during any applicable Regulatory Process.
- 5.1.6 The Municipality acknowledges and agrees that it will not raise any issues or concerns to the applicable Governmental Authorities during any applicable Regulatory Process with respect to any comments that it provided to NWMO in accordance with Section 5.1.2 that were addressed and incorporated by NWMO into the applicable final Project Application Materials in accordance with Section 5.1.3.
- 5.1.7 The Municipality will make good faith efforts to collaborate with other municipalities that receive capacity funding from NWMO with respect to the

retention of consultants for the purposes of reviewing any Project Application Materials.

- 5.1.8 The Municipality acknowledges and agrees that all Project Application Materials, including drafts of such Project Application Materials and all notes, analysis, summaries or other documents prepared by either Party in respect thereof, shall be treated as Confidential Information and shall not be disclosed to any Person other than in accordance with Article 15.

5.2 Participation in Regulatory Processes

- 5.2.1 The Municipality agrees to support NWMO in any Regulatory Process. Without limiting the generality of the foregoing, the Municipality agrees to:

- (a) at the reasonable request of NWMO, submit support letters or provide other written evidence of support to applicable Governmental Authorities (other than the Municipality) in connection with the applications for Regulatory Approvals;
- (b) at the reasonable request of NWMO, attend regulatory hearings or meetings to support the Project and make oral submissions at such hearings or meetings in support of the Project;
- (c) not take the position in any Regulatory Process or otherwise, or support any Person (including any resident or other municipality) that takes the position, that NWMO should not be granted any Regulatory Approval or be permitted to undertake any activities in connection with the Project;
- (d) at the request of NWMO, provide information that the Municipality possesses to any Governmental Authority to support any applications for Regulatory Approvals;
- (e) subject to Article 14, process, review and render a decision in an expeditious manner regarding any applications made by NWMO for a Regulatory Approval within the Municipality's jurisdiction that is directly or indirectly related to the Project or this Agreement, including applications for Regulatory Approvals required in connection with the Centre of Expertise or to enable NWMO to meet its obligations under this Agreement. For clarity, such required Regulatory Approvals may include the Municipality passing by-laws, when and if required, in connection with the foregoing; and
- (f) meet its obligations in this Section 5.2.1 in a manner that assists NWMO in achieving its timelines associated with any Regulatory Process.

- 5.2.2 For greater certainty and without limiting the foregoing or the Municipality's other obligations set out in this Agreement, the Municipality shall comply with its obligations in Sections 4.2.1 and 4.2.3.

- 5.2.3 Nothing in this Section 5.2 shall be construed as limiting or in any way prohibiting the Municipality from making what it reasonably believes to be truthful statements to a Governmental Authority during a Regulatory Process, including any critical or negative views the Municipality may have of aspects of the Project.

5.3 IA Process and CNSC Licensing Process

- 5.3.1 The Municipality agrees to assist NWMO with its IA Process. Without limiting the generality of the foregoing, the Municipality agrees to:
- (a) attend workshops at NWMO's request; and
 - (b) provide information requested by NWMO in connection with any of the deliverables required pursuant to the IA Process, including the deliverables set out in Section 2.1 of Schedule E.
- 5.3.2 The Municipality agrees to assist NWMO with its licence applications made to the CNSC in connection with the Project by providing information requested by NWMO in connection with any of the deliverables required in connection with the applicable CNSC licensing process, including the deliverables set out in Section 2.2 of Schedule E.
- 5.3.3 NWMO shall determine the level of assistance required by the Municipality with respect to its obligations under Section 5.3.1 and Section 5.3.2, including the extent, form, and timing of such assistance. NWMO shall communicate such requirements to the Municipality promptly following provision of the deliverables, but, in any event, not less than eight (8) weeks prior to the applicable engagement, and the Municipality shall comply with all such requirements.
- 5.3.4 The Municipality shall meet its obligations in this Article 5 in a manner that assists NWMO in achieving its timelines associated with any Regulatory Process.

5.4 Provision of Project Information Materials

Upon the request of the Municipality, NWMO shall provide the Municipality's representatives on the Implementation Committee with an electronic copy of any of the Project Information Materials.

ARTICLE 6 PROJECT SCOPE MODIFICATIONS

6.1 Project Scope Modifications

- 6.1.1 The Municipality acknowledges and agrees that NWMO shall have the right, from time to time, to:

- (a) emplace additional used nuclear fuel in the DGR from Accepted Fuel Sources; and
- (b) emplace used nuclear fuel in the DGR from sources other than Accepted Fuel Sources (including used nuclear fuel from small modular reactors that have filed a licence application with the CNSC following the Effective Date),

(the “**Project Scope Modifications**” and each, a “**Project Scope Modification**”).

6.1.2 For clarity, NWMO acknowledges and agrees that additional used nuclear fuel emplaced in the DGR as a result of a Project Scope Modification shall comply with Section 2.2.3.

6.2 Project Scope Modification Process

6.2.1 If NWMO wishes to undertake a Project Scope Modification, it shall, prior to implementing such Project Scope Modification:

- (a) provide Notice to the Municipality describing: (i) the Project Scope Modification in sufficient detail to enable the Municipality to understand the anticipated impacts; (ii) any anticipated impact to the Anticipated Schedule; and (iii) any required Regulatory Approvals or any amendment required to any existing Regulatory Approvals resulting from such Project Scope Modification (a “**Project Scope Modification Notice**”); and
- (b) provide the Municipality with an opportunity to review and provide comments upon the Project Scope Modification Notice in accordance with the process set out in Section 5.1.

6.2.2 For clarity, the Municipality acknowledges and agrees that nothing in this Article 6 restricts NWMO’s right to undertake a Project Scope Modification (including, for greater certainty, applying for a Regulatory Approval or an amendment to an existing Regulatory Approval), provided that NWMO has complied with Section 6.2.1.

6.2.3 If the Operations Phase extends beyond the duration stipulated in the Anticipated Schedule as a result of a Project Scope Modification, NWMO shall pay the Municipality:

- (a) an annual Operating Payment equal to the Operating Payment paid in the final year of the Operations Phase, as set out in the Detailed Financial Benefits Table, until the Extended Monitoring Phase commences; and
- (b) the Emplacement Fee in respect of such additional used nuclear fuel.

ARTICLE 7 CONTRACTORS

7.1 Contractors

7.1.1 Each Party will ensure that its Contractors:

- (a) when performing such Party's obligations under this Agreement, comply with the applicable terms and conditions of this Agreement by flowing-down such terms and conditions in the contract entered into with each Contractor (including causing its Contractors to use commercially reasonable efforts to flow-down such applicable terms and conditions to any of its sub-subcontractors pursuant to the applicable sub-subcontract); and
- (b) do not take any action that such Party is not permitted to take under this Agreement,

and such Party will be fully responsible and liable if and to the extent that any of its Contractors: (i) fails to comply with any applicable terms and conditions of this Agreement; and/or (ii) takes any action that such Party is not permitted to take under this Agreement, in each case to the same extent as if such action or failure had been an action or failure of such Party hereunder.

7.1.2 Neither Party will be relieved of any liability or obligation under this Agreement by the delegation of any responsibilities to any Contractor.

ARTICLE 8 BUSINESS OPPORTUNITIES

8.1 Business Opportunities

The Parties: (a) acknowledge that, as of the Effective Date, given that the Project is in an early stage of development, it is premature to identify specific contracts and/or work scopes that may be made available to businesses based in the Municipality that meet the definition of a Local Business; and (b) agree that the NWMO shall, in conjunction with its negotiation of contracts with certain third parties in respect of the local development, construction and operation aspects of the Project, act in accordance with the Procurement Policy.

ARTICLE 9 EMPLOYMENT AND TRAINING

9.1 Local Employment and Training Program

- 9.1.1 NWMO is committed to facilitating employment opportunities for residents of the Municipality related to the Project.
- 9.1.2 After the Commencement Date, the Parties agree that the Implementation Committee shall form a Training and Employment Working Group (the “**T&E Working Group**”) to provide recommendations and advice in respect of the establishment and implementation of a local employment and training program for residents of the Municipality (the “**LET Program**”).
- 9.1.3 NWMO shall prepare and implement the LET Program, based on the following principles:
- (a) fostering local employment opportunities offered by NWMO and its Contractors during the Phases;
 - (b) utilizing existing training programs and post-secondary school co-op programs available to residents of the Municipality;
 - (c) collaborating with the Municipality on potential educational and training programs, including accessing funding from Governmental Authorities; and
 - (d) using commercially reasonable efforts to provide opportunities for summer jobs and paid internship positions in connection with the Project to young residents of the Municipality.

9.2 Monitoring and Reporting

The T&E Working Group shall prepare, or cause to be prepared, a biennial report in respect of the prior two (2) years of the Term for delivery to the Implementation Committee which: (a) sets out the status and progress of the implementation of the LET Program; and (b) provides recommendations to improve upon the implementation of the LET Program. The Implementation Committee shall, in consultation with the T&E Working Group, determine the timing for delivery of such report annually during the Term.

ARTICLE 10 PROJECT GOVERNANCE

10.1 Implementation Committee

- 10.1.1 Within ninety (90) days following the Commencement Date, the Parties shall establish an implementation committee in accordance with the terms of reference

set out in Schedule D in order to oversee the implementation of this Agreement (the “**Implementation Committee**”).

- 10.1.2 If requested by the Municipality, the Parties may, on an annual basis, schedule an information sharing meeting in respect of the upcoming relevant Regulatory Processes and elements of the Agreement with Ignace Council, new Implementation Committee representatives, and/or other Representatives of the Municipality. The aim of such meeting will be to support the Municipality’s capacity to participate in and benefit from input and decision-making opportunities in respect of the Project, as provided for in this Agreement. Where reasonably feasible and in the interest of efficiency, the Parties shall align the timing of any such information sharing meeting with a scheduled meeting of the Implementation Committee.

ARTICLE 11 FINANCIAL BENEFITS

11.1 Payments by NWMO to the Municipality

- 11.1.1 NWMO shall pay the financial benefits set out in Schedule B (the “**Financial Benefits**”) to the Municipality in accordance with the terms of Schedule B.
- 11.1.2 The Municipality acknowledges and agrees that: (i) payment of the Financial Benefits; (ii) delivery of the benefits set out in Schedule C; and (iii) any additional payments made in connection with a Project Scope Modification, Delay Period or Interruption of Operations:
- (a) compensate the Municipality for reasonably foreseeable impacts (whether direct or indirect) associated with the Project;
 - (b) compensate the Municipality for all costs and expenses incurred by the Municipality, directly or indirectly, in fulfilling its obligations under this Agreement (including the Capacity and Capability Commitment); and
 - (c) constitute full and final satisfaction of all amounts owed by NWMO to the Municipality in connection with this Agreement and the Project.
- 11.1.3 Further to Section 11.1.2, the Municipality hereby waives any right to any additional financial or other compensation in connection with this Agreement and the Project.
- 11.1.4 In order to maximize the impact of the Financial Benefits on the Municipality, the Municipality acknowledges and agrees that it shall use commercially reasonable efforts to source and secure additional funding, including participation in available federal or provincial government grant programs or other government initiatives, to aid in the achievement of the Community Vision. In the event that the

Municipality successfully obtains additional third party funding to supplement the Financial Benefits, the Municipality agrees to reallocate any surplus portion of the Financial Benefits to other municipal infrastructure or capital projects in a manner that is fiscally responsible and of benefit to the Municipality.

11.2 Delay Payments

11.2.1 The Parties acknowledge and agree that as of the Effective Date, NWMO anticipates that:

- (a) it will make a site selection decision for the Project by December 31, 2024; and
- (b) the Phases will occur in accordance with the Anticipated Schedule.

11.2.2 If NWMO receives a Notice from the Municipality that, based upon the Community Decision, the Municipality is a Willing Host and NWMO's site selection decision is delayed beyond December 31, 2024, NWMO agrees to continue funding the Municipality's costs associated with its participation in the site selection process for the Project until the earlier of the date that: (i) NWMO delivers the NWMO Site Selection Notice to the Municipality, or (ii) is four (4) years following the Community Decision. If NWMO fails to deliver an NWMO Site Selection Notice within four (4) years of the Community Decision, such failure shall be deemed to be an NWMO Exit Event and trigger the payment of the NWMO Exit Benefits to the Municipality.

11.2.3 If commencement of the Site Preparation Phase, Construction Phase, or Operations Phase is delayed beyond January 1st of the first (1st) year stipulated in the Anticipated Schedule (a "**Delay Period**"):

- (a) NWMO shall provide Notice to the Municipality of the occurrence of a Delay Period;
- (b) for the first (1st) year of any Delay Period, NWMO shall pay to the Municipality the Annual Payment payable in the final year of the current Phase;
- (c) for the second (2nd), third (3rd) and fourth (4th) year of any Delay Period, NWMO shall pay to the Municipality: (i) the Support Payment payable in the final year of the then current Phase; and (ii) Committed Costs in the then current year with respect to the amount identified under the "Infrastructure & Community Well-Being Fund" column in Exhibit 1 of Schedule B; and
- (d) for the fifth (5th) and any subsequent year of any Delay Period, NWMO shall make payments to the Municipality in accordance with Section 11.3.

11.2.4 For greater certainty, NWMO shall not be obligated to pay to the Municipality any Financial Benefits during any Delay Period, other than as set out in Section 11.2.3.

11.2.5 If the Operations Phase extends beyond the duration stipulated in the Anticipated Schedule as a result of a Project Scope Modification, NWMO shall pay the Annual Payment payable in the final year of the Operations Phase as set out in the Detailed Financial Benefits Table to the Municipality until the Extended Monitoring Phase commences.

11.2.6 NWMO's obligations under Section 11.2.3 in respect of a Delay Period shall terminate upon the commencement of the next Phase.

11.2.7 For greater certainty, all payments made pursuant to this Section 11.2 shall be paid in accordance with Schedule B.

11.3 Extended Delay

11.3.1 Prior to the end of the third (3rd) year of any Delay Period, the Parties shall require the Implementation Committee to meet by no later than February 28th of the fourth (4th) year of such Delay Period to consider:

- (a) the likelihood that: (i) the Delay Period will extend beyond the end of the fourth (4th) year of such Delay Period; and (ii) NWMO may terminate this Agreement as a result of such extended Delay Period;
- (b) potential measures that one or both of the Parties could take to end or shorten the Delay Period; and
- (c) whether further financial payments will be required by the Municipality beyond the end of the fourth (4th) year of any Delay Period to address costs incurred or to be incurred in connection with the Municipality's participation in the development of the Project, taking into account the Support Payments made to the Municipality and amounts spent by the Municipality during such Delay Period.

11.3.2 If, based upon the meeting held in accordance with Section 11.3.1, the Implementation Committee believes that the Delay Period could extend beyond the end of the fourth (4th) year of such Delay Period, the Implementation Committee shall, by no later than April 30th of the fourth (4th) year of such Delay Period, prepare and deliver a report to the Parties which contains:

- (a) its findings and any recommendations;
- (b) a work plan to implement any such recommendations; and
- (c) if the Implementation Committee considers necessary, recommendations in respect of any payments that NWMO should make to the Municipality in the fifth (5th) and subsequent years of the Delay Period to compensate the Municipality for costs incurred or to be incurred in connection with its participation in the development of the Project.

11.3.3 The Parties shall: (a) review and consider the Implementation Committee's report delivered in accordance with Section 11.3.2; and (b) negotiate any changes, amendments or modifications to this Agreement in order to address such Delay Period that extends beyond the end of the fourth (4th) year of such Delay Period.

11.4 Interruption of Operations

11.4.1 If, during the Operations Phase, NWMO determines, as a result of any act, event, cause or condition beyond its control, that it will not be emplacing used nuclear fuel in the DGR for a period of twelve (12) months, or such longer period as provided for in this Section 11.4 (an "**Interruption of Operations**"):

- (a) NWMO shall provide Notice to the Municipality of the Interruption of Operations;
- (b) for the first (1st) year of any Interruption of Operations, NWMO shall pay to the Municipality the Annual Payment payable in accordance with Schedule B;
- (c) for the second (2nd) and third (3rd) year of any Interruption of Operations, NWMO shall pay to the Municipality: (i) the Support Payment in respect of each such year; and (ii) Committed Costs incurred in respect of the amount(s) identified under the "Infrastructure & Community Well-Being Fund" column in Exhibit 1 of Schedule B for the second (2nd) and/or third (3rd) year of any Interruption of Operations, as applicable, but not to exceed such amount; and
- (d) for the fourth (4th) and any subsequent year(s) of any Interruption of Operations, NWMO shall make payments to the Municipality in accordance with Section 11.5.

11.4.2 For greater certainty, NWMO shall not be obligated to pay to the Municipality any Financial Benefits during any Interruption of Operations, other than as set out in Section 11.4.1.

11.4.3 NWMO's obligations under Section 11.4.1 shall terminate upon the earlier of the date that NWMO: (i) resumes emplacement of used nuclear fuel in the DGR; and (ii) delivers Notice to the Municipality that NWMO is permanently ceasing the emplacement of used nuclear fuel in the DGR (a "**Permanent Cessation Notice**").

11.4.4 For greater certainty, all payments made pursuant to this Section 11.4 shall be paid in accordance with Schedule B.

11.5 Extended Interruption of Operations

11.5.1 Prior to the end of the second (2nd) year of any Interruption of Operations, the Parties shall require the Implementation Committee to meet by no later than February 28th of the third (3rd) year of such Interruption of Operations to consider:

- (a) the likelihood that: (i) the Interruption of Operations will extend beyond the end of the third (3rd) year of such Interruption of Operations; and (ii) NWMO may issue a Permanent Cessation Notice; and
- (b) whether further financial payments will be required by the Municipality beyond the end of the third (3rd) year of any Interruption of Operations to address costs incurred or to be incurred in connection with the Municipality's participation in the development of the Project, taking into account the Support Payments made to the Municipality and amounts spent by the Municipality during the Interruption of Operations.

11.5.2 If, based upon the meeting held in accordance with Section 11.5.1, the Implementation Committee agrees that it anticipates that the Interruption of Operations could extend beyond the end of the third (3rd) year, the Implementation Committee shall, by no later than April 30th of the third (3rd) year of the Interruption of Operations, prepare and deliver a report to the Parties that contains:

- (a) its findings and any recommendations;
- (b) a work plan to implement any such recommendations; and
- (c) if the Implementation Committee considers necessary, recommendations in respect of any payments that NWMO should make to the Municipality in the fourth (4th) and subsequent years of the Interruption of Operations to compensate the Municipality for costs incurred or to be incurred in connection with its participation in the development of the Project.

11.5.3 The Parties shall: (a) review and consider the Implementation Committee's report delivered in accordance with Section 11.5.2; and (b) negotiate any changes, amendments or modifications to this Agreement in order to address such Interruption of Operations that extends beyond the third (3rd) year, or to address the reduction in the duration of the Operations Phase.

11.5.4 Following the end of the third (3rd) year of any Interruption of Operations, and provided that NWMO has complied with this Section 11.5, NWMO may deliver a Permanent Cessation Notice to the Municipality.

11.6 Adjustment to the Anticipated Schedule

Once a Delay Period or Interruption of Operations has ended and the next Phase has commenced or NWMO has resumed the emplacement of used nuclear fuel in the DGR, as applicable, the Anticipated Schedule and the Detailed Financial Benefits Table shall be adjusted on a year-for-year basis to account for the applicable Delay Period or Interruption of Operations and NWMO shall resume its payment of Financial Benefits to the Municipality pursuant to this Agreement in accordance with the revised Anticipated Schedule and Detailed Financial Benefits Table. For clarity, the Parties acknowledge and agree that any adjustments required to the Detailed Financial Benefits Table in accordance with this Section 11.6 shall be made using 2025 constant dollars.

11.7 Suspension of Payments

- 11.7.1 In the event NWMO alleges that the Municipality has failed to comply with its obligations under this Agreement (a “**Municipality Default**”), NWMO shall deliver Notice to the Municipality thereof, which Notice shall include a description of the alleged default and, if applicable, the actions required to cure or otherwise remedy the same with reasonable specificity (a “**Notice of Default**”). Where possible, the Municipality shall promptly cure or otherwise remedy the Municipality Default identified in such Notice of Default, but, in any event, within thirty (30) days of the date of such Notice of Default (or such shorter period identified by NWMO in the Notice of Default if significant legal, financial, economic, or other consequences would likely result from providing thirty (30) days for the Municipality Default to be cured).
- 11.7.2 In the event that the Municipality disputes the claims made in a Notice of Default, the Municipality may invoke the Dispute resolution process set out in Article 17.
- 11.7.3 If the Municipality: (i) does not dispute the claims made in a Notice of Default, and has not cured such Municipality Default within the cure period prescribed in the Notice of Default; or (ii) has disputed the claims made in a Notice of Default and such Dispute is resolved in favour of NWMO, and has not cured such Municipality Default within the cure period prescribed in the Notice of Default following the date that the Dispute is resolved in favour of NWMO, NWMO may:
- (a) suspend payment of any Financial Benefits or other payments or amounts owed to the Municipality which are payable pursuant to this Agreement as of the date of such Notice of Default until such Municipality Default is cured;
 - (b) where possible and necessary for the Project (as determined by NWMO in its sole discretion), perform, or cause to be performed, the Municipality’s obligations identified in the applicable Notice of Default; and
 - (c) set-off any liabilities, damages, costs and expenses, including reasonable legal fees, (collectively, “**Losses**”) incurred by NWMO in connection with such Municipality Default against unpaid Financial Benefits or other payments or amounts owed to the Municipality pursuant to this Agreement.
- 11.7.4 NWMO shall pay the Financial Benefits or other payments or amounts owed that were suspended pursuant to Section 11.7.3(a), less any amounts deducted pursuant to Section 11.7.3(c), to the Municipality within thirty (30) days of the date that the Municipality Default has been cured.

ARTICLE 12 ADDITIONAL BENEFITS

12.1 Additional Benefits

NWMO shall deliver the additional benefits set out in Schedule C.

ARTICLE 13 EMERGENCY SERVICES

13.1 Emergency Services

13.1.1 Prior to the issuance of the Licence to Prepare Site, NWMO will:

- (a) prepare, or cause to be prepared, an emergency response plan (the “**Project Emergency Response Plan**”); and
- (b) investigate and identify emergency services required from the Municipality and/or the Kenora District Services Board (“**KDSB**”) that fall outside of the Project Emergency Response Plan (each, a “**Local Emergency Service**”).

13.1.2 NWMO agrees that it shall endeavour, subject to any regulatory constraints, to include the Municipality in the preparation of the Project Emergency Response Plan and investigation and identification of Local Emergency Services, as set out in Section 13.1.1.

13.1.3 After the Commencement Date but prior to the start of any activities to be performed under the Licence to Construct, NWMO will enter into a mutual aid agreement (the “**MAA**”) with the Municipality and/or the KDSB, as applicable, with respect to any required Local Emergency Services identified pursuant to Section 13.1.1(b). The MAA will, without limitation and with such necessary changes, variations, modifications, and alterations as determined at the time of execution of the MAA:

- (a) define, and if applicable quantify, the supported needs, capabilities, capacities and funding instruments that will be required by each Local Emergency Service to functionally support the Facility; and
- (b) allocate responsibility to NWMO for any incremental costs resulting from:
 - (i) the provision of the Local Emergency Services to the Facility; and
 - (ii) any incremental updates to the Project Emergency Response Plan and/or any other emergency response plans developed in respect of the Facility, that are attributable to the Facility.

- 13.1.4 NWMO also agrees, subject to any regulatory constraints, to work with the Municipality to identify a suitable representative of the Municipality that will be invited to participate in the committee established pursuant to the Project Emergency Response Plan.

ARTICLE 14 MUNICIPAL AUTHORITY

14.1 No Derogation of Municipality Authority

- 14.1.1 All applications made by NWMO for a Regulatory Approval within the Municipality's jurisdiction shall be considered by the appropriate municipal officer based solely on the merits of the application and in the same manner as the appropriate municipal officer would do with any other similar application from any other Person. The Municipality shall process, review and render a decision on any such application in a timely manner to enable NWMO to meet its obligations under this Agreement.
- 14.1.2 Nothing in this Agreement shall be interpreted as requiring the Municipality to approve any application for a Regulatory Approval within the Municipality's jurisdiction that is directly or indirectly related to the Project or this Agreement, except as the Municipality would do with any similar application from any other Person. NWMO acknowledges that this Agreement is not intended to have the effect of, expressly or impliedly, fettering the legislative or regulatory discretion of the current or future Ignace Council in this regard.
- 14.1.3 Nothing in this Agreement shall be interpreted as restricting the exercise of any right of appeal or review available to NWMO under Applicable Law in the event the Municipality refuses to approve an application made by NWMO for a Regulatory Approval within the Municipality's jurisdiction.

14.2 Inquiry under the *Municipal Affairs Act* (Ontario)

- 14.2.1 The Parties acknowledge that: (a) sections 20 and 21 of the *Municipal Affairs Act* (Ontario) enable the Ontario Land Tribunal (the "**Tribunal**") to conduct an inquiry into the financial status of a municipality (an "**Inquiry**"); and (b) if the Tribunal is satisfied that certain conditions are met, it may make an order vesting control over the affairs of a municipality in the Ministry of Municipal Affairs and Housing.
- 14.2.2 The Municipality agrees to: (a) promptly, and in any event within three (3) Business Days, deliver Notice to NWMO if it intends to request that the Tribunal conduct an inquiry pursuant to section 20 of the *Municipal Affairs Act* (Ontario) or if it has received notice of such a request from another Person; (b) not object should NWMO wish to seek to participate in such Inquiry; and (c) provide NWMO with a copy of any document filed with the Tribunal related to the request for an Inquiry.

- 14.2.3 In the event that an Inquiry is initiated, the Municipality agrees that NWMO shall, upon delivery of Notice, have the right to hold all Financial Benefits in a segregated account controlled by NWMO (the “**Segregated Account**”). Upon delivery of such Notice, NWMO shall make payments from the Segregated Account to third parties for the purposes of covering costs incurred in support of the performance of the Municipality’s obligations pursuant to this Agreement (paid from amounts allocated for such costs, as identified in the Detailed Financial Benefits Table).

ARTICLE 15 CONFIDENTIALITY

15.1 Definition of Confidential Information

- 15.1.1 For the purposes of this Agreement, “**Confidential Information**” means any information provided by a Party or its Representatives on the one hand (each, a “**Disclosing Party**”), to the other Party or its Representatives on the other hand (the “**Receiving Party**”), in connection with this Agreement, before and after the Effective Date.
- 15.1.2 Confidential Information shall not include any information which the Receiving Party can conclusively establish:
- (a) was already lawfully in the possession of the Receiving Party on a non-confidential basis or lawfully known to the Receiving Party on a non-confidential basis prior to the disclosure of such information by or on behalf of the Disclosing Party;
 - (b) is or was lawfully and independently developed by the Receiving Party, or on its behalf, by Persons having no access to Confidential Information at the time of such independent development;
 - (c) is at the time of disclosure or thereafter becomes part of the public domain through no breach of the Receiving Party’s confidentiality obligations under this Agreement; or
 - (d) is lawfully obtained by the Receiving Party from an independent Person under no legal obligation to maintain the confidentiality of such information.

15.2 Treatment of Confidential Information

- 15.2.1 The Receiving Party shall maintain the confidential nature of Confidential Information and shall take reasonable steps to protect Confidential Information from unauthorized use, access and disclosure using at least those measures that it takes to protect its own Confidential Information of a similar nature, but no less than reasonable care. Confidential Information shall not be used by the Receiving

Party nor published, communicated or otherwise disclosed by the Receiving Party to any Person pursuant to Section 15.3 except: (a) as may be required for the performance of the Receiving Party's obligations under this Agreement and in accordance with this Agreement; or (b) as may be required by a Party or its Representatives in connection with the Project.

15.2.2 The Parties acknowledge and agree that, notwithstanding this Article 15, they shall handle and disclose Confidential Information in accordance with Applicable Law, including any applicable export control regulations.

15.3 Disclosure of Confidential Information

15.3.1 Notwithstanding Section 15.2, the Receiving Party may disclose Confidential Information of the Disclosing Party:

- (a) with the prior written consent of the Disclosing Party;
- (b) to its Representatives who have a need to know such Confidential Information, provided that such Representatives have been informed of the Receiving Party's confidentiality obligations set out in this Article 15 and are bound by confidentiality obligations substantially similar in nature and effect, and at least as stringent as, the Receiving Party's confidentiality obligations hereunder;
- (c) as may be required pursuant to Applicable Law, provided that:
 - (i) where permitted by Applicable Law, prior to any such disclosure, the Disclosing Party shall be promptly notified by the Receiving Party of the proposed disclosure and the Receiving Party shall, at the Disclosing Party's request, take reasonable steps to allow the Disclosing Party, at the Disclosing Party's sole cost, to contest the requirement for disclosure and/or limit the disclosure of Confidential Information to only such portions as are required by Applicable Law or to obtain an order or ruling to preserve the confidentiality of such Confidential Information; and
 - (ii) the Receiving Party shall (A) only disclose that portion of the Confidential Information that it is required to disclose, and (B) use commercially reasonable efforts to ensure that such Confidential Information is afforded confidential treatment;
- (d) in accordance with Section 15.4;
- (e) except and to the extent that legal privilege applies to such Confidential Information, as necessary in connection with any Dispute between the Parties so long as such disclosure is made on a confidential basis in accordance with Article 17; and

- (f) to a Governmental Authority, in connection with obtaining and/or maintaining or renewing any Regulatory Approval.

15.3.2 The Receiving Party shall be responsible for any breach of this Article 15 by any of its Representatives. The Receiving Party shall take reasonable measures, including court proceedings to restrain its Representatives from making unauthorized disclosure or use of Confidential Information of the Disclosing Party.

15.3.3 The Receiving Party shall provide Notice to the Disclosing Party of the existence of any unauthorized disclosure, possession or use of the Disclosing Party's Confidential Information, including details of the circumstances surrounding such unauthorized disclosure, possession or use, promptly after discovery of that unauthorized disclosure, possession, or use of the Disclosing Party's Confidential Information by any Person. The Receiving Party shall co-operate with the Disclosing Party to stop such unauthorized disclosure, possession or use.

15.4 Access to Information

15.4.1 The Parties acknowledge and agree that the Municipality is subject to the *Municipal Freedom of Information and Protection of Privacy Act* (Ontario) (collectively, along with any other access to information, freedom of information or any other public disclosure law applicable to the Municipality, "**MFIPPA**"), and that any disclosure by the Municipality of any of NWMO's Confidential Information that is legally required to be disclosed under MFIPPA shall be permitted in accordance with this Section 15.4, notwithstanding anything else in this Article 15.

15.4.2 The Municipality agrees that, in the event it receives an access request under MFIPPA for Confidential Information received from NWMO, the Municipality shall (i) fully comply with its obligations under MFIPPA in responding to such a request, and (ii) provide such cooperation and support, as it deems appropriate and consistent with its obligations under MFIPPA, to NWMO in maintaining the confidentiality of the Confidential Information, including to:

- (a) promptly, and within the required timeframes under MFIPPA, notify NWMO of such a request;
- (b) assert any and all applicable exemptions under MFIPPA (including, having regard to any representations made by NWMO, any applicable exemption provided for trade secrets and proprietary commercial, financial, technical or scientific information) to protect such information from disclosure;
- (c) support any appeal or other efforts by NWMO to obtain an order or other appropriate remedy to prevent the disclosure of such information;
- (d) not disclose any such information unless required by a final order made under MFIPPA; and

- (e) disclose only the portion of the information that it determines, after consultation with its Representatives, it is legally required to disclose.

15.4.3 The Parties acknowledge and agree that each NWMO Member and such NWMO Member's shareholders may be subject to certain Federal and Provincial legislation relating to privacy, access to information and freedom of information (collectively, "**Privacy Legislation**"), and that any disclosure by any NWMO Member or its shareholders of any of the Municipality's Confidential Information pursuant to applicable Privacy Legislation shall be permitted, notwithstanding anything else in this Article 15.

15.4.4 The Parties acknowledge and agree that the *Access to Information Act* (Canada) (the "**AIA**") may apply to Confidential Information disclosed by either Party to a Governmental Authority. Each Party shall take whatever measures are commercially reasonable under the AIA to preserve the confidentiality of such Confidential Information.

15.4.5 The provisions of this Section 15.4 shall prevail over and in lieu of any other applicable provisions in this Agreement that conflict with the provisions of this Section 15.4.

15.5 Injunctive Relief

15.5.1 The Parties agree that monetary damages may not be a sufficient remedy for any breach by a Receiving Party or any of its Representatives of its, or their, obligations pursuant to this Article 15 and that, in addition to all other remedies at law or in equity to which the Disclosing Party may be entitled, the Disclosing Party may be entitled to specific performance and injunctive or other equitable relief as a remedy for any such breach.

15.5.2 Each Party involved in a legal proceeding seeking such injunctive relief in a court of competent jurisdiction outside the Dispute resolution process set out in Article 17 has the right to disclose in such legal proceedings Confidential Information as required by and in such legal proceedings.

ARTICLE 16 COMMUNICATIONS

16.1 Communications

The Parties shall comply with the Communications Protocol.

ARTICLE 17 DISPUTE RESOLUTION

17.1 Dispute Resolution Process

- 17.1.1 If a dispute arises in relation to any matter under this Agreement either Party may deliver to the other Party a Notice (the “**Dispute Notice**”) describing in reasonable detail the dispute, controversy, or claim arising out of or relating to any provision of this Agreement, or the alleged wrongful exercise or failure to exercise by a Party of a discretion or power given to that Party under this Agreement (collectively and individually, a “**Dispute**”).
- 17.1.2 The Parties agree to resolve any Dispute following the process set out in Section 17.1. Any resolution to a Dispute pursuant to Section 17.1.4 and Section 17.1.5 shall not be binding on the Parties until approved by both Parties in writing. The processes set out in Section 17.1.4 to Section 17.1.6 shall be the exclusive mechanism for resolving any Dispute and are express conditions precedent to arbitration of a Dispute pursuant to Section 17.1.7.
- 17.1.3 Notwithstanding the foregoing, if a Party (for the purposes of this Section 17.1.3, the “**Initial Party**”): (a) is made a party to any court proceedings brought by a third party; or (b) initiates any court proceedings against a third party in respect of the Project, then the Dispute may be resolved through the court proceeding, provided that: (i) if requested by the Initial Party, the other Party consents to being added as a party to such proceeding; and (ii) if requested by the other Party, the Initial Party consents to the other Party being added as a necessary party to such proceeding. For clarity, the Parties acknowledge and agree that, where possible, Disputes shall be resolved pursuant to arbitration in accordance with this Article 17 and that this Section 17.1.3 is not intended to permit a Party to initiate a Dispute in court where it could otherwise be resolved by arbitration (including joining other relevant third parties who have agreed to participate in the arbitration).
- 17.1.4 The Parties agree that any Dispute shall be first referred to the Implementation Committee for resolution. At the time the Dispute Notice is delivered by a Party to the other Party, the Party commencing such Dispute shall concurrently provide a copy of the Dispute Notice to the Implementation Committee.
- 17.1.5 If, within twenty (20) Business Days of delivery of the Dispute Notice to the Implementation Committee, the Implementation Committee has not resolved the Dispute, the Dispute shall be referred to the President of NWMO and the Mayor of the Municipality or their designate for resolution.
- 17.1.6 If, within ten (10) Business Days of the date the Dispute was referred to the President of NWMO and the Mayor of the Municipality or their designate for resolution, such representatives of the Parties have not resolved the Dispute, then either Party has the right to refer the Dispute to arbitration in accordance with Section 17.1.7.

17.1.7 If a Dispute is referred to arbitration, the Parties agree that:

- (a) arbitration pursuant to this Section 17.1.7 shall be the sole and exclusive remedy for the resolution of a Dispute submitted to arbitration;
- (b) the arbitration shall be conducted in accordance with the Rules of Arbitration of the ADR Institute of Canada in effect on the Effective Date or such other arbitration rules mutually agreed to by the Parties (the “**Arbitration Rules**”), except to the extent such Arbitration Rules conflict with the provisions of this Section 17.1.7, in which case the provisions of this Section 17.1.7 shall prevail;
- (c) the Parties shall be entitled to seek interim measures of protection from the courts of the province of Ontario pending completion of any arbitration, including seeking an interim or interlocutory injunction;
- (d) the arbitral tribunal shall consist of one (1) arbitrator appointed in accordance with this Section 17.1.7;
- (e) the arbitrator appointed by the Parties to resolve a Dispute shall be an individual with experience in the subject matter of the Dispute;
- (f) the Parties shall jointly appoint an arbitrator within twenty (20) Business Days of the date the Dispute is referred to arbitration. If the Parties are unable to mutually agree upon an arbitrator for such Dispute, for any reason whatsoever, such arbitrator shall be appointed by the ADR Institute of Canada in accordance with the Arbitration Rules and this Section 17.1.7;
- (g) the arbitration shall be heard in Thunder Bay, Ontario, unless the Parties otherwise agree in writing, and English shall be the language of the arbitration proceedings;
- (h) the arbitrator shall apply, and shall be bound by, Applicable Law and the terms of the Agreement;
- (i) the Parties may disclose any relevant Confidential Information to the arbitrator for the purposes of arbitration of the Dispute;
- (j) all arbitration hearings shall constitute Confidential Information to which Article 15 applies. Any arbitrator appointed pursuant to this Section 17.1.7 shall keep all information and documents relating to the Dispute confidential and shall not disclose such information or documents to anyone other than the Parties, unless required to do so by Applicable Law. Any arbitrator appointed pursuant to this Section 17.1.7 shall not be compellable as a witness in any subsequent proceeding and their working papers shall not be subject to subsequent production, unless required by Applicable Law;

- (k) arbitrations shall be governed by the laws of the Province of Ontario;
- (l) the arbitrator shall decide the Dispute and shall state in writing the reasons for the decision;
- (m) any monetary award of the arbitrator shall be denominated in Canadian funds and shall be paid in accordance with the time period specified by the arbitrator by wire transfer to an account designated in writing by the Party receiving such award;
- (n) unless the Parties otherwise agree and subject to Sections 17.1.3 and 17.1.8, no Dispute, controversy or claim hereunder shall be consolidated with any arbitral or other proceeding involving any third party;
- (o) unless the Parties expressly agree in writing to the contrary, the Parties undertake to keep confidential all awards in the arbitration, together with all materials in the proceedings created for the purpose of the arbitration and all other documents produced by another Party in the proceeding not otherwise in the public domain, provided that each of the Parties shall be entitled to disclose such matters to its Representatives, to the extent required by Applicable Law, and may make such disclosures in the course of any proceedings required to protect or pursue any legal right arising out of or in connection with the arbitration or a challenge of an award;
- (p) the Parties shall equally share the fees of the arbitrator and the costs of arbitration (other than each Party's legal fees);
- (q) the Parties shall each bear their own legal costs of the arbitration;
- (r) notwithstanding Section 17.1.7(p) and Section 17.1.7(q), the arbitrator may order the losing Party to pay all or a portion of the costs of arbitration and the legal fees of the successful Party if the arbitrator is of the view that the losing Party's claim or defence was frivolous; and
- (s) any decision of the arbitrator in respect of a Dispute shall be final and binding on the Parties, provided that a Party may appeal such decision, but only in respect of a question of law.

17.1.8 The Parties acknowledge that they have a strong desire to avoid a multiplicity of proceedings relating to the resolution of Disputes involving common issues and to have such common issues resolved in a single forum. As such, in the event that a dispute arises under another agreement related to the Project which involves a Party (for the purposes of this Section 17.1.8, the "**Initial Party**"), including a subcontract between a Party and any of its Contractors, and/or an agreement between NWMO and any local community or Local Indigenous Community, if requested by the Initial Party, the other Party consents to the joinder of any arbitration proceedings thereunder with any arbitration proceedings under this Agreement.

17.2 Exclusions

17.2.1 Notwithstanding anything contained in this Agreement to the contrary, Section 17.1 shall not apply to:

- (a) the Municipality's determination of whether the Municipality is or is not a Willing Host under Section 4.2.1;
- (b) NWMO's decision to select or not select the Project Area as the site for the Project;
- (c) the processing or denial of any Regulatory Approval within the Municipality's jurisdiction under Article 14, provided the Municipality has complied with the requirements of Section 14.1.1; and
- (d) the applicable Party's decision to disclose Confidential Information pursuant to Article 15.

ARTICLE 18 REPRESENTATIONS AND WARRANTIES

18.1 Representations and Warranties of NWMO

18.1.1 NWMO acknowledges that the Municipality is relying upon the representations set out in this Agreement and in connection with its entering into this Agreement, NWMO represents and warrants as follows:

- (a) NWMO is a duly constituted not-for-profit organization;
- (b) NWMO is validly existing, and is in good standing with the relevant Governmental Authority, under the federal laws of Canada;
- (c) NWMO has all necessary powers, capacity and authority to enter into this Agreement and to perform the obligations as set out herein, and to do all acts and things, and execute, deliver and perform all other agreements, instruments, undertakings and documents as are explicitly or implicitly required by this Agreement to be done, executed, delivered or performed by NWMO;
- (d) this Agreement has been duly authorized, executed and delivered by NWMO and constitutes a legal, valid and binding obligation on NWMO, enforceable against NWMO in accordance with its terms, subject only to:
 - (i) limitations with respect to the enforcement of remedies by bankruptcy, insolvency, moratorium, winding-up, arrangement, reorganization, fraudulent preference and conveyance and other laws of general application affecting the enforcement of creditors' rights generally; and

- (ii) general equitable principles and the fact that the availability of equitable remedies is in the discretion of a court and that a court may stay proceedings or the execution of judgments;
- (e) the execution and delivery by NWMO and the performance by NWMO of its obligations under this Agreement do not violate or conflict with, or constitute a default under:
 - (i) NWMO's constating, formation or organizational documents, including any by-laws;
 - (ii) any Applicable Law; or
 - (iii) any covenant, contract, agreement, or understanding to which NWMO is a party;
- (f) NWMO is financially solvent, able to pay its debts as they mature, and is, or will be, possessed of sufficient working capital to complete its obligations as they arise under this Agreement; and
- (g) to NWMO's knowledge, there are no actions, suits, proceedings, or investigations pending or threatened (in writing) against NWMO that could have a material impact on its ability to fulfill its obligations under this Agreement.

18.1.2 All of the representations and warranties of NWMO set forth in Section 18.1.1 are true and correct on the Effective Date and NWMO covenants that the representations and warranties set forth in Section 18.1.1 shall continue to be true and correct throughout the Term. NWMO shall provide the Municipality with Notice if any of the representations and warranties of NWMO set forth in Section 18.1.1 was false or inaccurate on the Effective Date or becomes false or inaccurate at any time during the Term, such notice to be provided no later than five (5) Business Days after NWMO becomes aware of such falsity or inaccuracy.

18.2 Representations and Warranties of the Municipality

18.2.1 The Municipality acknowledges that NWMO is relying upon the representations and warranties set out in this Agreement and in connection with its entering into this Agreement, the Municipality represents, warrants and covenants as follows:

- (a) the Municipality is a duly incorporated municipal corporation;
- (b) the Municipality is validly existing, and is in good standing with the relevant Governmental Authority, under the laws of Ontario;
- (c) Ignace Council has approved this Agreement and the entering into of such Agreement and has provided a copy of the Ignace Council resolution dated as of the Effective Date evidencing such approval to NWMO;

- (d) the Municipality has all necessary powers, capacity and authority to enter into this Agreement and to perform the obligations as set out herein, and to do all acts and things, and execute, deliver and perform all other agreements, instruments, undertakings and documents as are explicitly or implicitly required by this Agreement to be done, executed, delivered or performed by the Municipality;
- (e) this Agreement has been duly authorized, executed and delivered by the Municipality and constitutes a legal, valid and binding obligation on the Municipality, enforceable against the Municipality in accordance with its terms, subject only to:
 - (i) limitations with respect to the enforcement of remedies by bankruptcy, insolvency, moratorium, winding-up, arrangement, reorganization, fraudulent preference and conveyance and other laws of general application affecting the enforcement of creditors' rights generally; and
 - (ii) general equitable principles and the fact that the availability of equitable remedies is in the discretion of a court and that a court may stay proceedings or the execution of judgments;
- (f) the execution and delivery by the Municipality and the performance by the Municipality of its obligations under this Agreement do not violate or conflict with, or constitute a default under:
 - (i) the Municipality's constating, formation or organizational documents, including any by-laws;
 - (ii) any Applicable Law; or
 - (iii) any covenant, contract, agreement, or understanding to which the Municipality is a party;
- (g) the Municipality is financially solvent, able to pay its debts as they mature, and is, or will be, possessed of sufficient working capital to complete its obligations as they arise under this Agreement; and
- (h) to the Municipality's knowledge, there are no actions, suits, proceedings, or investigations pending or threatened (in writing) against the Municipality that could have a material impact on its ability to fulfill its obligations under this Agreement.

18.2.2 All of the representations and warranties of the Municipality set forth in Section 18.2.1 are true and correct on the Effective Date and the Municipality covenants that the representations and warranties set forth in Section 18.2.1 shall continue to be true and correct throughout the Term. The Municipality shall provide NWMO with Notice if any of the representations and warranties of the Municipality

set forth in Section 18.2.1 was false or inaccurate on the Effective Date or becomes false or inaccurate at any time during the Term, such Notice to be provided no later than five (5) Business Days after the Municipality becomes aware of such falsity or inaccuracy.

ARTICLE 19

EXIT AND TERMINATION BENEFITS

19.1 Municipality Exit Event

19.1.1 In the event that a Municipality Exit Event occurs, NWMO shall:

- (a) pay the Municipality \$5,000,000 in accordance with Section 19.5; and
- (b) grant the Municipality the LMC Option, which may be exercised in accordance with Section 19.6.1,

(collectively, the “**Municipality Exit Benefits**”).

19.1.2 For clarity, the Parties acknowledge and agree that if the Municipality has failed to deliver Notice to NWMO that the Municipality is or is not a Willing Host by September 30, 2024, NWMO may, in its sole discretion, deem that a Municipality Exit Event has occurred as of the date that NWMO delivers Notice to that effect to the Municipality.

19.2 NWMO Exit Event

19.2.1 In the event that an NWMO Exit Event occurs, NWMO shall:

- (a) pay the Municipality \$8,000,000 in accordance with Section 19.5; and
- (b) grant the Municipality the LMC Option, which may be exercised in accordance with Section 19.6.1,

(collectively, the “**NWMO Exit Benefits**”).

19.3 NWMO Termination Event

19.3.1 In the event that an NWMO Termination Event occurs, NWMO may terminate this Agreement in accordance with Section 19.4.4 and shall:

- (a) enter into negotiations with the Municipality to agree upon the termination payment to be made in connection with such NWMO Termination Event. Such termination payment shall be limited to:
 - (i) Committed Costs, which shall not exceed \$6,000,000 in aggregate; and

- (ii) in order to allow for a reasonable wind-down period, the payment of certain support costs that the Municipality has committed to prior to the occurrence of the NWMO Termination Event. For clarity, such support costs shall not exceed \$600,000 in aggregate; and

- (b) grant the Municipality the LMC Option, which may be exercised in accordance with Section 19.6.1,

(collectively, the “**NWMO Termination Benefits**”).

19.4 Exit Benefits and NWMO Termination Benefits

19.4.1 NWMO agrees to deliver the applicable Exit Benefits or NWMO Termination Benefits in accordance with Section 19.5 and Section 19.6, as applicable.

19.4.2 Notwithstanding Section 19.4.1 and anything in this Agreement to the contrary, NWMO shall not be required to deliver the applicable Exit Benefits or NWMO Termination Benefits to the Municipality if NWMO determines that: (a) the NWMO Exit Event or NWMO Termination Event is caused or contributed to, in whole or in part or directly or indirectly, by the Municipality’s actions or inactions; or (b) at the time that an NWMO Exit Event or NWMO Termination Event occurs, a Municipality Default has occurred and is continuing.

19.4.3 If the Municipality disputes NWMO’s determination pursuant to Section 19.4.2, the Parties agree that such Dispute shall be resolved in accordance with the Dispute resolution process set out in Article 17.

19.4.4 Upon delivery of the applicable Exit Benefits or NWMO Termination Benefits, this Agreement shall terminate and, subject to Section 20.2, be of no further force and effect.

19.5 Payment of Financial Portion of the Exit Benefits or NWMO Termination Benefits

19.5.1 Subject to Sections 19.4.2 and 22.2 NWMO shall pay the monetary portion of:

- (a) the applicable Exit Benefits to the Municipality on or prior to the date that is sixty (60) days following the occurrence of the applicable Exit Event; or
- (b) the NWMO Termination Benefits to the Municipality on or prior to the date that is sixty (60) days following completion of negotiations of the monetary portion of the NWMO Termination Benefits in accordance with Section 19.3.1(a),

in each case by wire transfer of immediately available funds in accordance with wire instructions provided by the Municipality to NWMO in writing.

19.6 Transfer of the Learn More Centre

19.6.1 For the period of six (6) months following either: (a) an Exit Event; or (b) the delivery of Notice from NWMO to the Municipality, pursuant to Section 2 of Schedule C, that NWMO no longer intends to use the Learn More Centre, the Municipality shall have an option to purchase the Learn More Centre (the “**LMC Option**”).

19.6.2 If the Municipality delivers Notice to NWMO that it wishes to exercise the LMC Option, the following shall apply to such purchase by the Municipality of the Learn More Centre from NWMO:

- (a) within sixty (60) days of the date that the Municipality delivers Notice of its intent to exercise its option to purchase the Learn More Centre, the Parties shall enter into an agreement of purchase and sale for the Learn More Centre using the Ontario Real Estate Association’s standard form of agreement of purchase and sale for commercial property (the “**Purchase and Sale Agreement**”);
- (b) the Parties agree that the value of consideration for the purchase of the Learn More Centre shall be \$1.00;
- (c) the Municipality agrees that it shall purchase the Learn More Centre on an “as is, where is” basis;
- (d) NWMO shall pay any taxes and related transaction costs associated with the purchase and sale of the Learn More Centre; and
- (e) each Party agrees that it shall do any such acts that are reasonably required and requested by the other Party to complete the purchase by the Municipality of the Learn More Centre from NWMO.

19.7 Full and Final Benefits

19.7.1 In the event that an Exit Event or NWMO Termination Event occurs, the Municipality:

- (a) acknowledges and agrees that the applicable Exit Benefits or NWMO Termination Benefits: (i) compensate the Municipality for all impacts (whether direct or indirect) related to the Project; and (ii) constitute full and final satisfaction of (A) all amounts owed by NWMO to the Municipality in connection with this Agreement and/or the Project, and (B) any present or future claims, demands and proceedings by the Municipality in respect of the Project and/or NWMO;
- (b) irrevocably waives any right to any additional financial or other compensation from NWMO in respect of the Project; and

- (c) releases NWMO from all liability in relation to this Agreement and the Project, and agrees that it shall be precluded from exercising all other rights and remedies in respect of any liability whether based upon an action or claim in contract, tort, warranty, equity, negligence, strict liability, intended conduct or otherwise.

ARTICLE 20

TERM AND TERMINATION

20.1 Term and Termination

This Agreement shall commence on the Effective Date and continue until the earlier of: (a) completion of the Extended Monitoring Phase; and (b) the date that this Agreement is terminated in accordance with Section 19.4.4 (the “**Term**”).

20.2 Provisions Surviving Termination of the Agreement

20.2.1 Notwithstanding the expiration of the Term:

- (a) each Receiving Party shall continue to keep confidential all Confidential Information of the Disclosing Party;
- (b) any monies due and owing shall be paid promptly, upon final calculation, to the Party to which such monies are owed by the Party which owes such monies, and any accounting for such monies required under this Agreement shall be thereafter forthwith provided by the Party receiving such monies to the Party paying such monies; and
- (c) Section 4.2.3(a), Section 4.2.3(b), Section 4.2.3(f), Article 15, Article 17, Section 19.5, Section 19.6, Section 19.7, Article 21, Section 22.10, Section 22.11, Sections 1.7 to 1.10 and Section 2 of Schedule C and any other provisions of this Agreement which are expressed to survive termination or which are required to give effect to such provisions which survive termination or to such termination or the consequences of such termination shall survive the termination of this Agreement.

ARTICLE 21

NOTICES

21.1 Notices

- 21.1.1 Any notice, demand, offer, or other written instrument required or permitted to be given pursuant to this Agreement shall be in writing and signed by the Party giving

such notice and shall be sent by mail or electronic mail to the other Party at such address as set forth below:

(a) if delivered to NWMO:

Address: 22 St. Clair Avenue East, 4th Floor
Toronto, Ontario M4T 2S3

Attention: Doug Taylor, Vice-President, General Counsel
Email: dtaylor@nwmo.ca

(b) if delivered to the Municipality:

Address: PO Box 248, 34 Highway 17 West
Ignace, Ontario, POT 1TO

Attention: Mayor Kimberly Baigrie
Email: kbaigrie@ignace.ca

21.1.2 Any Party shall have the right to change the place to which such notice shall be sent or delivered by similar notice sent in like manner to the other Party. The effective date of any notice issued pursuant to this Agreement shall be the date of the addressee's receipt of such notice.

ARTICLE 22 GENERAL PROVISIONS

22.1 Assignment

Neither Party shall have any right to assign this Agreement or any interest herein to any other Person without the prior written consent of the other Party, which consent may be withheld at that Party's sole discretion.

22.2 Set-off

NWMO shall be entitled to set-off any amount owing to the Municipality hereunder against any amount owed by the Municipality to NWMO. NWMO shall deliver Notice to the Municipality prior to implementing such set-off. The Parties acknowledge and agree that the set-off rights set out in this Section 22.2 shall only apply to this Agreement.

22.3 No Partnership

Nothing in this Agreement shall be construed as creating a legal partnership, joint venture or association or a trust, fiduciary, or similar relationship. It is further understood and agreed that no Party is liable for the acts, covenants, and agreements of the other Party, except as may be expressly provided in this Agreement.

22.4 Entire Agreement

This Agreement constitutes the entire agreement between the Parties pertaining to the subject matter of this Agreement and supersedes all other prior agreements and undertakings, both written and oral, among the Parties with respect to the subject matter hereof. There are no warranties, conditions, or representations (including negligent misrepresentations and any that may be implied by statute) and there are no promises, covenants or agreements (including collateral contracts) in connection with such subject matter except as specifically set forth or referred to in this Agreement. No reliance is placed on any warranty, representation (including negligent misrepresentation), promise, covenant, agreement, opinion, advice or assertion of fact made either prior to, contemporaneous with, or after entering into this Agreement, or any amendment or supplement thereto, by any Party to this Agreement or its Representatives to the other Party to this Agreement or its Representatives, except to the extent that the same has been reduced to writing and included as a term of this Agreement, and neither of the Parties to this Agreement have been induced to enter into this Agreement or any amendment or supplement by reason of any such warranty, representation (including negligent misrepresentation), promise, covenant, agreement, opinion, advice or assertion of fact. Accordingly, there shall be no liability, either in tort (including negligence and negligent misrepresentation) or in contract, assessed in relation to any such warranty, representation (including negligent misrepresentation), promise, covenant, agreement, opinion, advice or assertion of fact, except to the extent contemplated above.

22.5 Amendment

No change, amendment or modification of this Agreement shall be valid or binding upon the Parties hereto unless such change, amendment, or modification shall be in writing and executed by all Parties.

22.6 Successor and Assigns

This Agreement shall enure to the benefit of and be binding upon the Parties and their respective successors and permitted assigns, which shall mean any successor to either Party in accordance with any legislation providing for the same. For greater certainty, the Parties acknowledge and agree that where the Municipality amalgamates or restructures, this Agreement shall enure to the benefit of and be binding upon the municipal corporation resulting from such amalgamation or restructuring.

22.7 No Waiver

Any waiver of, or consent to depart from, the requirements of any provision of this Agreement shall be effective only if it is in writing and signed by the Party giving it, and only in the specific instance and for the specific purpose for which it has been given. No failure on the part of any Party to exercise, and no delay in exercising, any right under this Agreement shall operate as a waiver of that or any future right. No single or partial exercise of any such right shall preclude any other or further exercise of that right or the exercise of any other right.

22.8 Severability

The invalidity of one or more of the phrases, sentences, clauses, Articles or Sections contained in this Agreement shall not affect the validity of the remaining portion of the Agreement so long as the material purposes of this Agreement can be determined and effectuated. If any provision of this Agreement or its application to any Party or circumstance is restricted, prohibited or unenforceable, that provision shall be ineffective only to the extent of that restriction, prohibition or unenforceability without invalidating the remaining provisions of this Agreement. In the event of such restriction, prohibition or unenforceability, the Parties shall make good faith efforts to negotiate a provision to replace the impugned provision so as to maintain the intent and purpose of this Agreement.

22.9 Further Assurances

Each of the Parties to this Agreement hereby agrees that it shall promptly do, make, execute or deliver, or cause to be done, made, executed or delivered, all such further acts, documents and things as the other Party may reasonably require from time to time for the purpose of giving effect to the provisions of this Agreement and each of the Parties to this Agreement agrees that it shall use reasonable efforts and take all such steps as may be reasonably within its power to implement to their full extent the provisions of this Agreement.

22.10 Governing Law

This Agreement shall be governed by, and interpreted and enforced in accordance with, the laws of the Province of Ontario and the laws of Canada applicable therein.

22.11 Jurisdiction

Subject to Article 17, the Parties hereby irrevocably attorn to the exclusive jurisdiction of the courts of the Province of Ontario and all courts competent to hear appeals therefrom.

22.12 Counterparts and Transmission

This Agreement and any amendment, supplement, restatement or termination of any provision of this Agreement may be executed and delivered in any number of counterparts, each of which when executed and delivered is an original but all of which taken together constitute one and the same instrument. A Party's transmission by facsimile, e-mail attachment (PDF document), or other electronic means, of a copy of this Agreement duly executed by that Party shall constitute effective delivery by that Party of an executed copy of this Agreement to the Party receiving the transmission. A Party that has delivered this Agreement by facsimile shall forthwith deliver an originally executed copy to the other Party.

[Remainder of this page left intentionally blank.]

IN WITNESS WHEREOF the Parties have duly executed this Agreement as of the Effective Date.

**NUCLEAR WASTE MANAGEMENT
ORGANIZATION**

<Original Signed by Laurie Swami; President and CEO>

**THE CORPORATION OF THE
TOWNSHIP OF IGNACE**
<Original Signed by Kimberly Baigrie; Mayor>

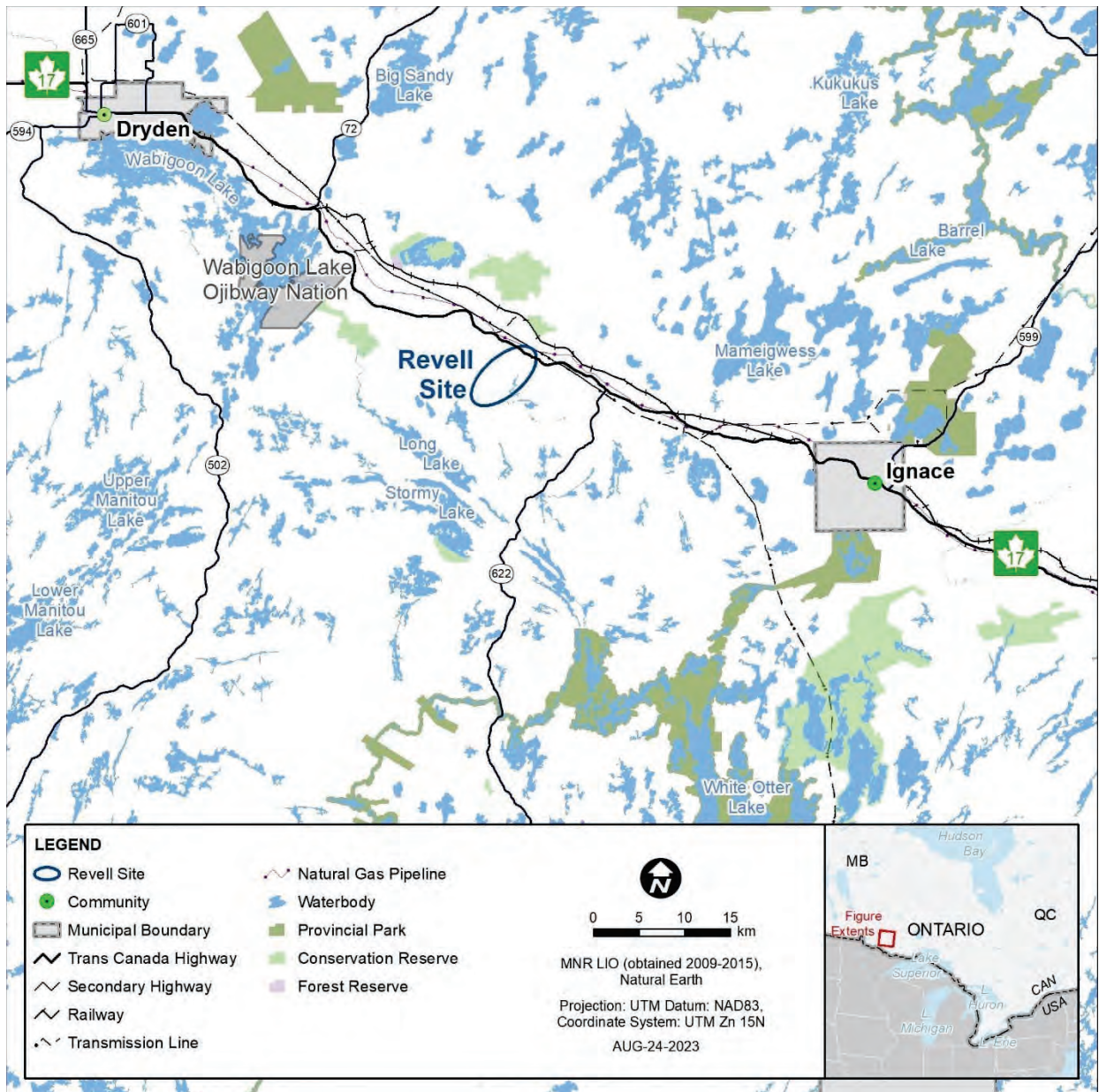


<Original Signed by Laurie Swami>

SCHEDULE A

PROJECT AREA

NWMO anticipates that the Project Area will be located in or around the area identified on the map below as the “Revell Site”. The detailed coordinates for the Project Area will be ascertained during the Licensing Phase based on the surface and subsurface area requirements for the Project developed in connection with: (a) the IA Process; and (b) other relevant Regulatory Processes with other Governmental Authorities. The Parties acknowledge and agree that the Agreement shall be amended during the Licensing Phase to replace this Schedule A once additional detail regarding the Project Area is available.



SCHEDULE B

FINANCIAL BENEFITS

The Financial Benefits payable by NWMO to the Municipality are comprised of: (a) Milestone Payments; (b) Annual Payments; and (c) an Emplacement Fee. Additional detail in respect of such payments streams is set out below and in the table attached as Exhibit 1 of this Schedule B (the “**Detailed Financial Benefits Table**”).

1. Milestone Payments.

1.1 NWMO shall make the following milestone payments (each, a “**Milestone Payment**”) to the Municipality upon the occurrence of the following:

- (a) \$1,500,000, upon NWMO’s receipt of written confirmation that the Municipality has completed its Willingness Process, and an additional \$500,000 if the Municipality provides written confirmation to NWMO, on or before June 30, 2024, that the Municipality has completed its Willingness Process;
- (b) if the Project Area is selected as the site for the Project:
 - (i) \$4,000,000, upon submission of the Initial Project Description to the IA Agency;
 - (ii) \$4,000,000, upon submission of the Final Impact Statement to the IA Agency and the application for the Licence to Prepare Site to the CNSC;
 - (iii) \$6,000,000, upon the CNSC’s issuance of the Licence to Construct;
 - (iv) \$6,000,000, upon the CNSC’s issuance of the Licence to Operate; and
 - (v) \$6,000,000, upon NWMO’s permanent cessation of emplacement of used nuclear fuel in the DGR, and NWMO’s delivery of the Permanent Cessation Notice to the Municipality,

(each, a “**Milestone Event**”).

1.2 For clarity, each Milestone Payment shall be payable once, upon achievement of the applicable Milestone, and no Milestone Payment shall be payable for subsequent or repeated achievements of such Milestone Events.

1.3 NWMO shall make Milestone Payments to the Municipality within ninety (90) days following the occurrence of the applicable Milestone Event.

2. Annual Payments.

2.1 Commencing on January 1st in the year following the Commencement Date, NWMO shall make an annual payment to the Municipality that is comprised of:

- (a) payments to compensate the Municipality for the costs associated with the Municipality's participation in the development of the Project, including payments in respect of (i) deliverable-driven engagement, and (ii) capacity support and governance (collectively, a "**Support Payment**"). See the columns identified under the heading "SUPPORT PAYMENT" in Exhibit 1 of this Schedule B for a detailed summary of the Support Payments that will be paid by NWMO to the Municipality during the Term;
- (b) payments to provide the Municipality with direct benefits, including payments in respect of (i) infrastructure and community well-being, and (ii) youth community training (collectively, a "**Benefits Payment**"). See the columns identified under the heading "BENEFITS PAYMENT" in Exhibit 1 of this Schedule B for a detailed summary of the Benefits Payment that will be paid by NWMO to the Municipality during the Term; and
- (c) an annual operating payment (an "**Operating Payment**"). See the column identified under the heading "OPERATING PAYMENT" in Exhibit 1 of this Schedule B for a detailed summary of the Operating Payments that will be paid by NWMO to the Municipality during the Term,

(together, each Support Payment, Benefit Payment and Operating Payment made in a given year constitutes an "**Annual Payment**").

2.2 NWMO shall pay all Annual Payments in quarterly installments within thirty (30) days of January 1st, April 1st, July 1st and October 1st during each year of the Term.

2.3 Subject to the occurrence of an NWMO Termination Event or delivery of a Permanent Cessation Notice by NWMO to the Municipality as a result of an Interruption of Operations, NWMO acknowledges and agrees that, in the event that any Phase is completed prior to December 31st in the year stipulated in the Anticipated Schedule (as may be such dates may be adjusted on a year-for-year basis to account for the applicable Delay Period or Interruption of Operations in accordance with Section 11.6), it shall pay the Municipality, as a lump sum, all amounts payable for the remainder of such Phase, as stipulated in the Detailed Financial Benefits Table (expressed in 2025 constant dollars and adjusted in accordance with Section 4.2 of Schedule B for the year that such Phase is completed).

3. Emplacement Fee.

3.1 NWMO shall pay an emplacement fee equal to \$0.50 for each Bundle that is emplaced in the DGR (the "**Emplacement Fee**").

- 3.2 The Emplacement Fee shall be paid in annual installments which shall be calculated based upon the number of Bundles emplaced in the DGR during the preceding year of the Operations Phase, as documented in the then-current Annual Fuel Projection Report. Each annual payment in respect of the Emplacement Fee shall be paid by NWMO to the Municipality no later than sixty (60) days following the end of each applicable year during the Operations Phase.
- 3.3 Subject to the occurrence of an NWMO Termination Event, NWMO acknowledges and agrees that, regardless of the actual number of Bundles that are emplaced in the DGR, it shall pay the Municipality not less than \$3,720,000 during the Operations Phase in respect of the Emplacement Fee.
4. Escalation of Financial Benefits.
- 4.1 The Financial Benefits, including the amounts set out in Exhibit 1 of this Schedule B, are expressed in 2025 constant dollars.
- 4.2 Commencing on January 1, 2026, and each year thereafter during the Term, the Financial Benefits paid in such year shall be adjusted by multiplying (i) the Financial Benefits payable in such year; by (ii) the CPI Adjustment.
5. Discretionary Benefit.
- 5.1 In addition to the Financial Benefits described in Sections 1, 2 and 3 of this Schedule B, NMWO shall, subject to Section 5.2 of this Schedule B, provide the Municipality with funding in furtherance of:
- (a) the recommendations set out in the Housing and Infrastructure Plan;
 - (b) infrastructure or capital projects which are in alignment with the Community Principles and are beneficial to the residents of Municipality, as determined by Ignace Council;
 - (c) emergency services (excluding any incremental costs that NWMO is responsible for pursuant to 13.1.3(b)); and
 - (d) the implementation of any requests from the Municipality which result from NWMO's engagement and consultation process with the Municipality and its residents, as set out in Section 1.5 of Schedule C,
- (collectively, the “**Discretionary Benefit**”).
- 5.2 The Parties acknowledge and agree that:
- (a) the Discretionary Benefit shall not exceed \$10 million, in aggregate;

- (b) subject to Section 5.2(c) of this Schedule B, the Discretionary Benefit shall be available to the Municipality at any time following the Commencement Date; and
- (c) prior to NWMO funding any Discretionary Benefit: (i) the Municipality shall deliver a written proposal to NWMO which contains relevant supporting documentation and cost estimates; and (ii) the Parties shall promptly meet to discuss, incorporate any comments submitted by the Parties and jointly finalize and agree upon such proposal.

EXHIBIT 1
DETAILED FINANCIAL BENEFITS TABLE

Attached.

EXHIBIT 1
DETAILED FINANCIAL BENEFITS TABLE

Phase	Milestones	Year Number	Year	Milestone Payments	Operating Payments	Emplacement Fee	Support Payments		Benefit Payments		Total
							Deliverable driven engagement	Capacity Support and Governance	Infrastructure & Community Well-Being Fund	Youth community training	
	Totals - In 2025 constant dollars			27,500,000	86,768,000	3,720,000	4,000,000	11,687,600	30,000,000	6,286,500	169,962,100
Siting	Partnership Agreement in place by YE	1	2023	-	-	-	-	-	-	-	-
Siting		2	2024	1,500,000	-	-	-	-	-	-	1,500,000
Licensing	Submission of Initial Project Description to IAAC	3	2025	4,000,000	500,000	-	1,000,000	1,557,736	-	150,000	7,207,736
Licensing		4	2026	-	500,000	-	1,000,000	557,736	4,500,000	150,000	6,707,736
Licensing		5	2027	-	500,000	-	1,000,000	557,736	-	150,000	2,207,736
Licensing	Submission of Final Impact Statement and Licence to Prepare Site Application to IAAC and CNSC	6	2028	4,000,000	500,000	-	1,000,000	557,736	4,500,000	200,000	10,757,736
Licensing		7	2029	-	500,000	-	-	557,736	-	200,000	1,257,736
Licensing		8	2030	-	500,000	-	-	557,736	4,500,000	200,000	5,757,736
Licensing	Submission of CNSC Construction Licence Application	9	2031	-	500,000	-	-	557,736	-	170,000	1,227,736
Site Preparation		10	2032	-	500,000	-	-	557,736	4,500,000	170,000	5,727,736
Site Preparation		11	2033	-	750,000	-	-	349,486	-	140,000	1,239,486
Site Preparation	Construction Initiated	12	2034	6,000,000	750,000	-	-	349,486	4,000,000	140,000	11,239,486
Site Preparation		13	2035	-	750,000	-	-	349,486	-	140,000	1,239,486
Construction		14	2036	-	750,000	-	-	349,486	4,000,000	140,000	5,239,486
Construction		15	2037	-	750,000	-	-	349,486	-	140,000	1,239,486
Construction	Submit LTO Application	16	2038	-	750,000	-	-	349,486	4,000,000	140,000	5,239,486
Construction		17	2039	-	750,000	-	-	349,486	-	140,000	1,239,486
Construction		18	2040	-	750,000	-	-	349,486	-	140,000	1,239,486
Construction		19	2041	-	750,000	-	-	349,486	-	140,000	1,239,486
Construction	Construction Completed, LTO Granted	20	2042	-	750,000	-	-	349,486	-	140,000	1,239,486
Operations	Operations Initiated	21	2043	6,000,000	1,214,000	60,000	-	38,850	-	111,000	7,423,850
Operations		22	2044	-	1,214,000	60,000	-	38,850	-	111,000	1,423,850
Operations		23	2045	-	1,214,000	60,000	-	38,850	-	111,000	1,423,850
Operations		24	2046	-	1,214,000	60,000	-	38,850	-	111,000	1,423,850
Operations		25	2047	-	1,214,000	60,000	-	142,975	-	111,000	1,527,975
Operations		26	2048	-	1,214,000	60,000	-	38,850	-	111,000	1,423,850
Operations		27	2049	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		28	2050	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		29	2051	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		30	2052	-	1,214,000	60,000	-	142,975	-	83,250	1,500,225
Operations		31	2053	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		32	2054	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		33	2055	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		34	2056	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		35	2057	-	1,214,000	60,000	-	142,975	-	83,250	1,500,225
Operations		36	2058	-	1,214,000	60,000	-	38,850	-	83,250	1,396,100
Operations		37	2059	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		38	2060	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		39	2061	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		40	2062	-	1,214,000	60,000	-	142,975	-	55,500	1,472,475
Operations		41	2063	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		42	2064	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		43	2065	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		44	2066	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		45	2067	-	1,214,000	60,000	-	142,975	-	55,500	1,472,475
Operations		46	2068	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		47	2069	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		48	2070	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		49	2071	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		50	2072	-	1,214,000	60,000	-	142,975	-	55,500	1,472,475
Operations		51	2073	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		52	2074	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		53	2075	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		54	2076	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		55	2077	-	1,214,000	60,000	-	142,975	-	55,500	1,472,475
Operations		56	2078	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		57	2079	-	1,214,000	60,000	-	38,850	-	55,500	1,368,350
Operations		58	2080	-	1,214,000	60,000	-	43,900	-	55,500	1,373,400
Operations		59	2081	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		60	2082	-	1,214,000	60,000	-	104,125	-	55,500	1,433,625
Operations		61	2083	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		62	2084	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		63	2085	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		64	2086	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		65	2087	-	1,214,000	60,000	-	104,125	-	55,500	1,433,625
Operations		66	2088	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		67	2089	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		68	2090	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		69	2091	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		70	2092	-	1,214,000	60,000	-	104,125	-	55,500	1,433,625
Operations		71	2093	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		72	2094	-	1,214,000	60,000	-	-	-	55,500	1,329,500
Operations		73	2095	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		74	2096	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		75	2097	-	1,214,000	60,000	-	104,125	-	-	1,378,125
Operations		76	2098	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		77	2099	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		78	2100	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		79	2101	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		80	2102	-	1,214,000	60,000	-	104,125	-	-	1,378,125
Operations		81	2103	-	1,214,000	60,000	-	-	-	-	1,274,000
Operations		82	2104	-	1,214,000	60,000	-	-	-	-	1,274,000
Extended Monitoring	Monitoring Initiated	83	2105	6,000,000	-	-	-	-	-	-	6,000,000
Extended Monitoring		84	2106	-	-	-	-	-	-	-	-
Extended Monitoring		85	2107	-	-	-	-	-	-	-	-
Extended Monitoring		86	2108	-	-	-	-	-	-	-	-
Extended Monitoring		87	2109	-	-	-	-	-	-	-	-
Extended Monitoring		88	2110	-	-	-	-	-	-	-	-
Extended Monitoring		89	2111	-	-	-	-	-	-	-	-

EXHIBIT 1
DETAILED FINANCIAL BENEFITS TABLE

Phase	Milestones	Year Number	Year	Milestone Payments	Operating Payments	Emplacement Fee	Support Payments		Benefit Payments		Total
							Deliverable driven engagement	Capacity Support and Governance	Infrastructure & Community Well- Being Fund	Youth community training	
Extended Monitoring		90	2112	-	-	-	-	-	-	-	-
Extended Monitoring		91	2113	-	-	-	-	-	-	-	-
Extended Monitoring		92	2114	-	-	-	-	-	-	-	-
Extended Monitoring		93	2115	-	-	-	-	-	-	-	-
Extended Monitoring		94	2116	-	-	-	-	-	-	-	-
Extended Monitoring		95	2117	-	-	-	-	-	-	-	-
Extended Monitoring		96	2118	-	-	-	-	-	-	-	-
Extended Monitoring		97	2119	-	-	-	-	-	-	-	-
Extended Monitoring		98	2120	-	-	-	-	-	-	-	-
Extended Monitoring		99	2121	-	-	-	-	-	-	-	-
Extended Monitoring		100	2122	-	-	-	-	-	-	-	-
Extended Monitoring		101	2123	-	-	-	-	-	-	-	-
Extended Monitoring		102	2124	-	-	-	-	-	-	-	-
Extended Monitoring		103	2125	-	-	-	-	-	-	-	-
Extended Monitoring		104	2126	-	-	-	-	-	-	-	-
Extended Monitoring		105	2127	-	-	-	-	-	-	-	-
Extended Monitoring		106	2128	-	-	-	-	-	-	-	-
Extended Monitoring		107	2129	-	-	-	-	-	-	-	-
Extended Monitoring		108	2130	-	-	-	-	-	-	-	-
Extended Monitoring		109	2131	-	-	-	-	-	-	-	-
Extended Monitoring		110	2132	-	-	-	-	-	-	-	-
Extended Monitoring		111	2133	-	-	-	-	-	-	-	-
Extended Monitoring		112	2134	-	-	-	-	-	-	-	-
Extended Monitoring		113	2135	-	-	-	-	-	-	-	-
Extended Monitoring		114	2136	-	-	-	-	-	-	-	-
Extended Monitoring		115	2137	-	-	-	-	-	-	-	-
Extended Monitoring		116	2138	-	-	-	-	-	-	-	-
Extended Monitoring		117	2139	-	-	-	-	-	-	-	-
Extended Monitoring		118	2140	-	-	-	-	-	-	-	-
Extended Monitoring		119	2141	-	-	-	-	-	-	-	-
Extended Monitoring		120	2142	-	-	-	-	-	-	-	-
Extended Monitoring		121	2143	-	-	-	-	-	-	-	-
Extended Monitoring		122	2144	-	-	-	-	-	-	-	-
Extended Monitoring		123	2145	-	-	-	-	-	-	-	-
Extended Monitoring		124	2146	-	-	-	-	-	-	-	-
Extended Monitoring		125	2147	-	-	-	-	-	-	-	-
Extended Monitoring		126	2148	-	-	-	-	-	-	-	-
Extended Monitoring		127	2149	-	-	-	-	-	-	-	-
Extended Monitoring		128	2150	-	-	-	-	-	-	-	-
Extended Monitoring		129	2151	-	-	-	-	-	-	-	-
Extended Monitoring		130	2152	-	-	-	-	-	-	-	-
Extended Monitoring		131	2153	-	-	-	-	-	-	-	-
Extended Monitoring		132	2154	-	-	-	-	-	-	-	-
Extended Monitoring		133	2155	-	-	-	-	-	-	-	-
Extended Monitoring		134	2156	-	-	-	-	-	-	-	-
Extended Monitoring		135	2157	-	-	-	-	-	-	-	-
Extended Monitoring		136	2158	-	-	-	-	-	-	-	-
Extended Monitoring		137	2159	-	-	-	-	-	-	-	-
Extended Monitoring		138	2160	-	-	-	-	-	-	-	-
Extended Monitoring		139	2161	-	-	-	-	-	-	-	-
Extended Monitoring		140	2162	-	-	-	-	-	-	-	-
Extended Monitoring		141	2163	-	-	-	-	-	-	-	-
Extended Monitoring		142	2164	-	-	-	-	-	-	-	-
Extended Monitoring		143	2165	-	-	-	-	-	-	-	-
Extended Monitoring		144	2166	-	-	-	-	-	-	-	-
Extended Monitoring		145	2167	-	-	-	-	-	-	-	-
Extended Monitoring		146	2168	-	-	-	-	-	-	-	-
Extended Monitoring		147	2169	-	-	-	-	-	-	-	-
Extended Monitoring		148	2170	-	-	-	-	-	-	-	-
Extended Monitoring		149	2171	-	-	-	-	-	-	-	-
Extended Monitoring		150	2172	-	-	-	-	-	-	-	-
Extended Monitoring		151	2173	-	-	-	-	-	-	-	-
Extended Monitoring		152	2174	-	-	-	-	-	-	-	-
Decommissioning	Decommissioning Initiated	153	2175	-	-	-	-	-	-	-	-
Decommissioning		154	2176	-	-	-	-	-	-	-	-
Decommissioning		155	2177	-	-	-	-	-	-	-	-
Decommissioning		156	2178	-	-	-	-	-	-	-	-
Decommissioning		157	2179	-	-	-	-	-	-	-	-
Decommissioning		158	2180	-	-	-	-	-	-	-	-
Decommissioning		159	2181	-	-	-	-	-	-	-	-
Decommissioning		160	2182	-	-	-	-	-	-	-	-
Decommissioning		161	2183	-	-	-	-	-	-	-	-
Decommissioning		162	2184	-	-	-	-	-	-	-	-
Decommissioning		163	2185	-	-	-	-	-	-	-	-
Decommissioning		164	2186	-	-	-	-	-	-	-	-
Decommissioning		165	2187	-	-	-	-	-	-	-	-
Decommissioning		166	2188	-	-	-	-	-	-	-	-
Decommissioning		167	2189	-	-	-	-	-	-	-	-
Decommissioning		168	2190	-	-	-	-	-	-	-	-
Decommissioning		169	2191	-	-	-	-	-	-	-	-
Decommissioning		170	2192	-	-	-	-	-	-	-	-
Decommissioning		171	2193	-	-	-	-	-	-	-	-
Decommissioning		172	2194	-	-	-	-	-	-	-	-

SCHEDULE C
ADDITIONAL BENEFITS

1. Centre of Expertise.

- 1.1 Following the Commencement Date, NWMO agrees to establish a Centre of Expertise for the Project located in Ignace, Ontario (the “**Centre of Expertise**”).
- 1.2 The Municipality agrees that it will not charge any development fees to NWMO in respect of the Centre of Expertise. Notwithstanding the foregoing, NWMO agrees it will enter into negotiations with the Municipality in respect of the payment of capital charges that the Municipality may be required to incur solely for the benefit of the Centre of Expertise. In the event that NWMO is charged development fees by the Municipality in respect of the Centre of Expertise, NWMO shall have the right to deduct and set-off any such development fees paid to the Municipality from the Financial Benefits owed to the Municipality pursuant to this Agreement.
- 1.3 The Municipality will:
 - (a) inform NWMO of any municipal lands available for purchase by NWMO to site the Centre of Expertise;
 - (b) inform NWMO of its preference for where the Centre of Expertise may be sited;
 - (c) work collaboratively with NWMO to ensure that zoning considerations on preferred target locations for the Centre of Expertise align with NWMO needs, *Planning Act* (Ontario) needs, and outstanding potential site control agreement needs;
 - (d) provide NWMO with a scope and cost estimate of the capital charges that will be incurred in respect of the preferred target locations for the Centre of Expertise; and
 - (e) to the extent that the site selected by NWMO resides on lands owned by the Municipality, grant NWMO a right of first refusal in respect of the purchase of such lands from the Municipality at fair market value.
- 1.4 Subject to the Municipality’s compliance with Applicable Law, the Municipality agrees to work collaboratively with NWMO to address zoning, *Planning Act* (Ontario), and other site control matters in respect of the site selected by the Parties for the Centre of Expertise.
- 1.5 NWMO shall consult with the Municipality and its residents throughout the design process for the Centre of Expertise. In addition, following the Commencement Date and as part of the design process for the Centre of Expertise, NWMO shall: (a)

provide the Municipality with an opportunity to participate in its engagement and consultation process for the Centre of Expertise; and (b) as part of such engagement and consultation process, consider comments provided by the Municipality and its residents.

- 1.6 The Municipality agrees to make good faith efforts to collaborate with WLON and its members in connection with the design, development and operation of the Centre of Expertise.
- 1.7 If NWMO terminates this Agreement, NWMO may sell, lease or transfer the Centre of Expertise at NWMO's discretion; however, as part of its consideration of such potential transactions, NWMO shall take into consideration: (a) the acquiror's plans for the site, including but not limited to its ability to fund and maintain the Centre of Expertise; (b) the Community Principles; and (c) the net benefits for the Municipality.
- 1.8 In the event that NWMO is unable to sell, lease or transfer the Centre of Expertise in accordance with Section 1.7 of this Schedule C within three (3) years of the date of termination of this Agreement, NWMO shall decommission the Centre of Expertise.
- 1.9 NWMO agrees that it shall continue to maintain and fund the costs incurred in connection with the Centre of Expertise until such time as it is sold, leased, transferred or decommissioned.
- 1.10 The Municipality shall use reasonable efforts to cooperate with NWMO in connection with execution of NWMO's rights and obligations set out in Section 1.7 of this Schedule C.

2. Learn More Centre.

- 2.1 NWMO agrees that if, at any time during the Term, it determines that no longer intends to use the Learn More Centre (either following construction of the Centre of Expertise or such other time as determined by NWMO, in its sole discretion), NWMO shall deliver Notice to the Municipality granting it the LMC Option, which may be exercised in accordance with 19.6.1.
- 2.2 NWMO agrees that, during the period of time that it owns and operates the Learn More Centre, it shall exercise reasonable prudence in its upkeep and maintenance of the property and building.

3. Housing.

- 3.1 The Municipality shall undertake a municipal housing study (the "**Housing Study**") which will serve as the basis for development of a jointly developed housing and infrastructure plan that aligns with the Community Principles and meets the future needs of both Parties (the "**Housing and Infrastructure Plan**").

- 3.2 The Parties agree that, in order to ensure that the Housing Study reflects both Parties' future needs, they shall jointly develop and approve the Housing Study's terms of reference.

4. Transportation Hub and Emergency Services Base.

- 4.1 The Parties acknowledge and agree that, given the current stage of development of the Project, NWMO is not able to make a commitment to the Municipality in respect of the development of a transportation hub for the Project based in the Municipality (a "**Transportation Hub**") or emergency, medical and/or fire services for the Project based in the Municipality (an "**Emergency Services Base**").
- 4.2 Notwithstanding the foregoing, NWMO agrees to use commercially reasonable efforts, with active participation and inclusion of the Municipality, to: (a) assess the feasibility of; and (b) consult with relevant Governmental Authorities, NWMO's project team, Contractors and other relevant stakeholders, in respect of the development of a Transportation Hub and/or Emergency Services Base in the Municipality, taking into consideration the needs of the Project, Applicable Law, input from relevant Governmental Authorities, and the needs of other local communities.

5. Gravel.

- 5.1 During the Construction Phase, NWMO will use commercially reasonable efforts to deliver 1,000 cubic metres of A-gravel or 2 inch crushed gravel which meets the Ontario Provincial Standard Specification 1000 or 1001 ("**Gravel**") to the Municipality annually, subject to construction of the Facility producing Gravel, compliance with the Regulatory Approvals, Applicable Law, and any of NWMO and its Contractors' reasonable operational constraints.

SCHEDULE D
IMPLEMENTATION COMMITTEE

1. Constitution of the Implementation Committee

- 1.1 The Implementation Committee shall be composed of two (2) representatives from each of NWMO and the Municipality. NWMO agrees that, upon request, an additional representative of the Municipality may attend meetings of the Implementation Committee as an observer.
- 1.2 Each Party shall use reasonable efforts to ensure that, where appropriate, its representatives appointed to the Implementation Committee remain representatives for as long as possible. Each Party may, from time to time, replace its representative(s) by delivering Notice to the other Party.
- 1.3 A Party's representative on the Implementation Committee shall: (a) be authorized to represent their appointing Party on any matter related to the implementation of the Agreement; and (b) when required, seek approval from their appointing Party for decisions related to the implementation of the Agreement which will bind the Parties.

2. Roles and Responsibilities of the Implementation Committee

- 2.1 The roles and responsibilities of the Implementation Committee shall include the following:
 - (a) managing the implementation of this Agreement in accordance with its terms;
 - (b) identifying outstanding actions under this Agreement;
 - (c) developing terms of reference consistent with this Schedule D for any Working Group established by the Implementation Committee in accordance with Section 6 of this Schedule D, which shall set out, at minimum:
 - (i) the purpose, membership and responsibilities of each Working Group;
 - (ii) the conduct of each Working Group's meetings and frequency of such meetings;
 - (iii) the frequency and manner in which each Working Group shall report to the Implementation Committee; and

- (iv) the process and information requirements in respect of referring a disagreement between the members of a Working Group to the Implementation Committee for resolution;
- (d) providing a forum for communication and co-operative measures for supporting the participation of the Municipality and its residents in the Project;
- (e) providing recommendations, advice and input in connection with the completion of relevant obligations in connection with this Agreement;
- (f) reviewing and approving reports prepared by any Working Group;
- (g) reviewing any reports prepared by the Municipality or NWMO in connection with this Agreement and/or the Project;
- (h) implementing the Communications Protocol and approving any amendments to the Communications Protocol in accordance with its terms;
- (i) advising on issues or concerns, and resolving disagreements and disputes, referred to it by any Working Group;
- (j) resolving Disputes referred to it pursuant to Section 17.1.4;
- (k) regularly briefing the Parties on the status of implementation of this Agreement; and
- (l) preparing and providing to the Parties by July 31st of each year during the Term:
 - (i) (A) a report of the activities undertaken and decisions and recommendations made by the Implementation Committee for the previous year; and (B) an assessment of such activities against the annual workplan prepared in respect of such year;
 - (ii) the Annual Work Plan for the following year, in accordance with Section 5 of this Schedule D; and
 - (iii) a report assessing the effectiveness of the mandate of the Implementation Committee with recommendations and necessary modifications.

3. Decision-Making

- 3.1 All decisions, recommendations of, and reports from the Implementation Committee shall be made unanimously by its members in attendance.

- 3.2 No decision or recommendation can be made, and no report can be approved, by the Implementation Committee unless at least one (1) representative of each Party is present at the meeting.
 - 3.3 Each Party must comply with the decisions and recommendations made by the Implementation Committee.
- 4. Disputes
 - 4.1 If consensus cannot be reached in respect of a decision, recommendation or report, as applicable, any member of the Implementation Committee may refer the disagreement to Dispute resolution pursuant to Article 17.
- 5. Annual Work Plan
 - 5.1 The Implementation Committee shall develop, by July 31st of each year during the Term, a work plan in respect of implementation of the Agreement for the following year (each, an “**Annual Work Plan**”).
 - 5.2 Promptly following the Effective Date, the Implementation Committee shall develop the template to be used for each Annual Work Plan which shall be approved by the Parties.
 - 5.3 The Implementation Committee shall incorporate the work plans submitted by the Working Groups and approved by the Implementation Committee in accordance with Section 6.3 of this Schedule D into the applicable Annual Work Plan.
 - 5.4 Prior to developing an Annual Work Plan, NWMO shall provide to the Implementation Committee a detailed description of its anticipated activities in respect of the Project for the relevant year.
- 6. Working Groups
 - 6.1 The Implementation Committee may form working groups (each, a “**Working Group**”) as it deems appropriate.
 - 6.2 Each Working Group shall, by May 1st of each year, submit a work plan for the following year for approval by the Implementation Committee.
 - 6.3 The Implementation Committee shall review and approve each Working Group’s work plan, subject to any revisions the Implementation Committee deems necessary.
- 7. Conduct of Members
 - 7.1 Members of the Implementation Committee and any Working Group shall perform their duties and obligations free from the influence of any personal or other conflicting interest and where any member has knowledge of any actual or potential

conflict of interest (whether such potential conflict is direct or indirect) such member shall provide details of such actual or potential conflict of interest to the Implementation Committee.

- 7.2 Where the Implementation Committee is advised or aware of any such conflict of interest on the part of a member of the Implementation Committee or any Working Group, the matter shall be made known to the member of the Implementation Committee or Working Group alleged to have such conflict of interest and such member shall not participate in any deliberations or decisions or recommendations to which such conflict of interest applies.

8. Meetings of Implementation Committee

- 8.1 The Implementation Committee shall meet, and the meetings of the Implementation Committee shall be conducted, in accordance with the following:

- (a) The Implementation Committee shall meet in person or by videoconference, as determined by the members of the Implementation Committee.
- (b) The members of the Implementation Committee shall appoint one (1) member of the Implementation Committee to act as chair at meetings of the Implementation Committee. The position of chair shall rotate between a representative of the Municipality and an NWMO representative on an annual basis. An NWMO representative shall be chair for the year following the Effective Date. The chair shall be responsible for convening meetings of the Implementation Committee and for setting the agenda for the meetings. The chair shall have a vote in his/her capacity as a member of the Implementation Committee but shall not have a second casting vote for any decisions or recommendations of the Implementation Committee. If the chair is not in attendance at any meeting, another representative of that Party may chair the meeting.
- (c) A special meeting of the Implementation Committee may be called by one of the Parties upon no less than five (5) days' Notice to the other Party, which Notice shall contain the reason for the special meeting.
- (d) The Implementation Committee shall meet: (i) at least monthly during the Licensing Phase, Site Preparation Phase and Construction Phase; and (ii) at least six (6) times annually during the Operations Phase or more or less frequently during any Phase as reasonably required by the Municipality or by NWMO or as determined by the Implementation Committee.
- (e) Implementation Committee members shall be required to attend, and actively participate in, Implementation Committee meetings.
- (f) For there to be quorum for any meeting of the Implementation Committee, there shall be at least one (1) member of each Party. If quorum is not attained in any meeting, the chair or if not present any member who is present, shall

adjourn the meeting to a date that is not less than ten (10) Business Days later and give Notice of this new date to all Implementation Committee members and any members who attend on the new date shall constitute quorum.

- (g) Experts and advisors and Party representatives may attend Implementation Committee meetings from time to time if their attendance is necessary to facilitate the work of the Implementation Committee and provided the Parties are given advance Notice of their attendance, but they shall not have any say in any decision or vote of the Implementation Committee.
- (h) The Implementation Committee shall make decisions about its own procedure by consensus.

9. Minutes

- 9.1 Minutes of each meeting of the Implementation Committee must be taken and made available to the Parties promptly following the meeting. NWMO shall be tasked with recording minutes unless the Parties agree otherwise.

10. Cost

- 10.1 No additional funding will be available for the Implementation Committee activities unless the Implementation Committee delivers a request to NWMO in writing which contains: (a) an estimate of such costs; and (b) an explanation which demonstrates that such costs are necessary and explains how the estimated expenditure is an efficient and cost effective use of NWMO funds. NWMO shall, acting reasonably, promptly review and respond to any such written request. For clarity, all such proposed expenditures shall comply with NWMO's then-current business expense policy and shall only be approved where the activities are directly in support of the performance by the Implementation Committee of the Parties' obligations set out in the Agreement.

SCHEDULE E
REGULATORY DECISION-MAKING DELIVERABLES

1. List of Project Application Materials:

1.1 The following impact assessment-related materials:

- (a) Initial Project Description – main submission, inclusive of the Public Engagement Report but exclusive of all technical appendices;
- (b) Impact Statement – main submission, inclusive of the Public Engagement Report but exclusive of all technical appendices;
- (c) Effects Assessment, exclusive of Indigenous Assessment topics; and
- (d) Mitigation, Monitoring and Commitments List.

1.2 The following CNSC licensing-related materials (applicable to each licence application made to the CNSC in respect of the Project):

- (a) Site Layouts;
- (b) Environmental Protection Plan;
- (c) Emergency Management and Fire Protection Plan; and
- (d) Waste Management Plan.

2. List of Deliverable Driven Engagement Materials:

2.1 The following impact assessment-related deliverables:

- (a) development of the baseline conditions;
- (b) establishment of the valued components for assessment;
- (c) determination and assessment of alternative means;
- (d) establishment of the spatial and temporal boundaries for the impact assessment;
- (e) establishment of criteria for the assessment of potential effects;
- (f) evaluation of cumulative effects;
- (g) identification of mitigation measures; and
- (h) establishment of monitoring plans.

2.2 The following CSNC licensing-related deliverables (applicable to each licence application made to the CNSC in respect of the Project):

- (a) Population & Land Use Report;
- (b) Preliminary Decommissioning Plan;
- (c) Emergency Planning (Management Report);
- (d) Groundwater Protection and Monitoring Plan; and
- (e) Environmental Monitoring Plan.

3. List of Project Information Materials:

3.1 Any materials required to be shared with the Municipality in connection with the IA Process.

3.2 The following CNSC licensing-related materials (applicable to each licence application made to the CNSC in respect of the Project):

- (a) Commission Member Document;
- (b) Exclusion Zone Report;
- (c) Secured Project Site Process;
- (d) Descriptive Geoscientific Site Model;
- (e) Waste Acceptance Criteria;
- (f) Reference Inventory Report;
- (g) Preliminary Pre-closure Safety Assessment;
- (h) Preliminary Post-closure Safety Assessment;
- (i) Effluent and Emissions Control / Monitoring; and
- (j) Site Prep Plan – Final.

3.3 Any materials that NWMO is required by a Governmental Authority (other than the Municipality) to share with the Municipality relating to any other Regulatory Process or Regulatory Approval not otherwise provided to the Municipality.

SCHEDULE F
COMMUNICATIONS PROTOCOL

1. GENERAL

1.1 Background

- (a) The Township of Ignace (the “**Municipality**”) and the Nuclear Waste Management Organization (“**NWMO**” and together with the Municipality, the “**Parties**” and each a “**Party**”) have entered into a Hosting Agreement dated March 18, 2024 in respect of the potential development of the Project in the Project Area (the “**Agreement**”). Capitalized terms used but not defined herein have the meaning set out in the Agreement.
- (b) This Communications Protocol shall govern and provide a framework for a coordinated approach to Communications (as defined below) between the Parties and with third parties in respect of the Agreement and/or the Project, and includes, among other things:
 - (i) each Party’s Communication Lead (as defined below), including the roles and responsibilities of the Communication Leads;
 - (ii) the Parties’ agreement upon the approach that will be taken in respect of the development of Communications and the Communications Work Plans (as defined below); and
 - (iii) the proposed communication tools to be used to keep the community and other stakeholders informed of progress of the Project.
- (c) Any communications not addressed by this Communications Protocol shall be governed by the Agreement. In the event of ambiguities, gaps, conflicts or inconsistencies between this Communications Protocol and the Agreement, the Agreement shall govern.
- (d) This Communications Protocol is designed to be flexible and responsive to the needs of the Parties as the Project progresses. The Communication Leads, with support from their respective Communications Team and the Implementation Committee, as required, shall be responsible for implementing this Communications Protocol on behalf of the Parties.

1.2 Communications Principles

- (a) The communications between the Parties will be guided by the following principles:
 - (i) mutual respect and understanding;

- (ii) flexibility, cooperation and openness;
- (iii) timely notification and sharing of information relevant to the Project; and
- (iv) recognition of the need to maintain open communications while respecting confidentiality pursuant to Article 15 of the Agreement.

1.3 Objectives

- (a) The objectives of this Communications Protocol are to coordinate the Parties' Communication Teams, processes and tactics in respect of Project to:
 - (i) generate support from partners, communities, and the public for the advancement of the Project and highlight the benefits that the Municipality and surrounding communities have and will receive in connection with the development of the Project;
 - (ii) keep Parties informed of any developments or communications that are relevant to the Project and/or that relate to or affect the other Party;
 - (iii) resolve any communications issues that emerge in connection with the Project that affect or relate to the Municipality;
 - (iv) plan and develop Communications in respect of Project development; and
 - (v) ensure that stakeholders, media, members of the public, partners and the Parties' employees are notified, informed, engaged and offered the opportunity to ask questions and provide feedback in respect of the Project.

1.4 Communications

- (a) For the purposes of this Communications Protocol, the Parties agree that "**Communications**" includes any media release, public event, campaign, public announcement or statement or other public disclosure (whether for publication in the press, on the radio, television, internet, social media or other medium) related to (i) in the case of the Municipality, the Agreement and the Project; and (ii) in the case of NWMO, the Agreement or the Project (only to the extent such Communication in respect of the Project relates to the Municipality).
- (b) For clarity, the Parties acknowledge and agree that Communications developed pursuant to the Communications Protocol could include:
 - (i) Branding, Graphics and Advertisements;
 - (ii) Media Releases (including information and quotes from each organization);
 - (iii) Supply Chain (including opportunities to highlight the Project's impact on local and Canadian supply chains);

- (iv) Social Media;
 - (v) Publications (including, where appropriate and applicable, the Parties will collaborate upon the development of information, quotes and pictures for inclusion in publications (*for example*, newsletters delivered to local residences, on NWMO's or the Municipality's website, etc.));
 - (vi) Industry Conferences (including opportunities to jointly attend and/or speak at such conferences);
 - (vii) Joint Public Information Sessions and Community Events; and
 - (viii) Thought Leadership (including jointly developing content and sharing individually developed content to help ensure coordination of efforts, consistent messaging, and to enhance opportunities to collectively amplify positive media coverage).
- (c) Each Party agrees that it will not issue, disseminate, hold, organize, publish or otherwise distribute any Communications other than in accordance with this Communications Protocol.

2. ROLES AND RESPONSIBILITIES

2.1 Communication Leads

- (a) Each Party will appoint a lead communications contact for the purposes of this Communications Protocol (the "**Communication Leads**" and each a "**Communication Lead**"). Each Party may, from time to time, replace its Communication Lead by delivering Notice to the other Party.
- (b) The Communication Leads shall:
 - (i) jointly develop the Communications Work Plans (as defined below) and implement such plans with the support of their Communications Teams;
 - (ii) schedule monthly meetings with the Communications Teams and delivering meeting minutes to the Implementation Committee for review and comment;
 - (iii) identify the need for and develop joint Ad-Hoc Communications (as defined below);
 - (iv) seek the approval of the Implementation Committee for Communications (as defined below) where the Communication Leads cannot agree;
 - (v) collaborate with the Parties' Communications Teams regarding Communication programs and messaging;

- (vi) support the Parties' Communication Team and liaise with the Implementation Committee to obtain the resources necessary to administer and execute upon this Communications Protocol; and
- (vii) undertake any other responsibilities delegated by the Implementation Committee from time to time.

3. ANNUAL COMMUNICATIONS WORK PLAN

3.1 Annual Communications Work Plan

- (a) On or prior to May 1st of each year during the Term, the Communication Leads shall jointly develop, and deliver to the Implementation Committee, a work plan in respect of Planned Communications (as defined below) for the next year (each, a **"Communications Work Plan"**). The Implementation Committee shall review and approve each Communication Work Plan.
- (b) In connection with the development of each Communications Work Plan, NWMO shall provide a detailed description of its anticipated activities in respect of the Project for the relevant year to the Communication Leads.
- (c) Each Communications Work Plan shall include the following:
 - (i) a list of the members of each Party's communications teams for that year (each, a **"Communications Team"**), including the roles and responsibilities of each team member;
 - (ii) (A) the anticipated activities in respect of the Project for that year that will be subject to joint Communications, and (B) any Communications that the Parties anticipate being required in that year, including communications to the residents of the Municipality (collectively, the **"Planned Communications"**);
 - (iii) the anticipated timing for each Planned Communication and the work schedule, including the tasks assigned to each Communications Team, for such Planned Communication;
 - (iv) the frequency, and proposed dates for, integration and alignment meetings to discuss the strategy, planning and updates related to the Planned Communications; and
 - (v) the communication tools and approaches which could be used to keep the residents of the Municipality informed regarding matters related to the Agreement and/or the Project.

4. AD-HOC COMMUNICATIONS

4.1 Ad-Hoc Communications Process

- (a) The Parties agree that this Section 4 applies to all Communications that are not Planned Communications in a given year, including requests from the media for comments or interviews (each, an “**Ad-Hoc Communication**”).

4.2 Residents of the Municipality

- (a) The Communication Leads will oversee the development of all Ad-Hoc Communications by the Parties to the residents of the Municipality in respect of the Agreement and/or the Project. The Communication Leads agree to use commercially reasonable efforts to engage the necessary internal resources of the Parties to develop and approve the Communication on the required timeline for such Communication.

4.3 Request for Ad-Hoc Communication

- (a) If a Party receives a request for an Ad-Hoc Communication, that Party (the “**Notifying Party**”) agrees to promptly notify the other Party’s (the “**Reviewing Party**”) Communication Lead and collaboratively develop the response to such request in accordance with this Section 4.3.
- (b) The Communication Leads will oversee, on behalf of the Notifying Party, the development of any Ad-Hoc Communication prepared in response to a request identified pursuant to Section 4.3(a). For any such Ad-Hoc Communication, the Communication Leads agree to use commercially reasonable efforts to engage the necessary internal resources to develop and approve such Ad-Hoc Communication on the required timeline.
- (c) If a request identified pursuant to Section 4.3(a) is received by the Notifying Party and requires:
 - (i) the issuance of an Ad-Hoc Communication by the Notifying Party outside of business hours (9 a.m. and 5 p.m.) on a Business Day or on a day that is not a Business Day; or
 - (ii) that the Notifying Party respond to such request urgently,that Notifying Party shall use commercially reasonable efforts to promptly notify the Reviewing Party’s Communication Lead. If, after using such commercially reasonable efforts, the Notifying Party is unable to reach the Reviewing Party’s Communication Lead, then that Notifying Party may issue an Ad-Hoc Communication without jointly developing such communication with the Reviewing Party’s Communication Lead. The Notifying Party shall develop such Ad-Hoc Communication having regard to the purpose and objectives of this Communications Protocol and that Party’s obligations under the Agreement.
- (d) If the Communication Leads are unable to agree upon the content of an Ad-Hoc Communication, the Communication Leads shall notify the Implementation Committee and the members of the Implementation Committee shall work together

in good faith to settle the Ad-Hoc Communication. If the Implementation Committee is unable to agree upon the content of an Ad-Hoc Communication submitted by the Communication Leads or otherwise, the Parties agree that (i) such Ad-Hoc Communications will not be circulated to any third party nor made public, and (ii) such Dispute shall be resolved in accordance with Article 17 of the Agreement.

5. ANNUAL REVIEW AND AMENDMENTS

5.1 Annual Review

- (a) The Communication Leads, along with other representatives from the Parties' Communications Teams, shall meet annually, or more frequently as determined by the Communication Leads, to discuss the implementation and undertake a review of this Communications Protocol. Based on such review, the Communication Leads will recommend amendments to this Communications Protocol for approval by the Parties in writing.

5.2 Amendments

- (a) Other than as a result of a review under Section 5.1, the Implementation Committee may, from time to time, recommend amendments to this Communications Protocol for approval by the Parties in writing.

SCHEDULE G
CAPABILITY AND CAPACITY COMMITMENT

(Attached)



The Corporation of the Township of Ignace

P O Box 248, 34 Hwy 17 West
Telephone: (807) 934-2202
Ignace, ON P0T 1T0
Telephone: (807) 934-2202
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March 18, 2024

Motion: #2024.03.18.055

Moved By:

- ☐ Mayor Kim Baigrie
- ☐ Councillor Jodie Defeo
- ☐ Councillor Janet Lett
- ☒ Councillor Wayne Minnear
- ☐ Councillor John Taddeo

Seconded By:

- ☐ Mayor Kim Baigrie
- ☒ Councillor Jodie Defeo
- ☐ Councillor Janet Lett
- ☐ Councillor Wayne Minnear
- ☐ Councillor John Taddeo

THAT, The Corporation of the Township of Ignace adopts the Statement of Commitment to Strategic Capability and Capacity Building.

AND FURTHER THAT, directs the Project Lead to move forward with the Post Multi Year Funding Strategic Study and will encompass the capability and capacity of building that strategic plan.

Voting Results:		Recorded Vote:			
Carried	✓	Voting Committee Members	Yes	No	Abstain
Defeated		Kim Baigrie			
Tabled		Jodie Defeo			
Recorded Vote		Janet Lett			
Pecuniary Interest Declared		Wayne Minnear			
Withdrawn		John Taddeo			
Deferred		<Original Signed by Kimberly Baigrie; Mayor>			

Ignace's Commitment to Building Capability and Capacity

To accommodate the hosting of the Deep Geological Repository near Ignace and the many evolutions and changes it will bring to Ignace and area the Council of Ignace recognizes that it is not enough just to be willing, the Township has to be able.

To be able Ignace has to have both the capability and the capacity to undertake the enormous growth that the DGR will bring to the area. The growth will be many faceted; economic, social, leisure, housing, governance, infrastructure to mention a few.

Capability and capacity are based on six strong basic pillars;

1. Structure, including communication
2. Management Systems
3. Enabling Policies
4. Competencies
5. Education
6. Leadership

Building and maintaining these pillars will be the key to success for Ignace. Without these pillars there will be no guidance or support for the changes required for the community to grow with the project. A program must be in place as the township moves forward in the process of accommodating the DGR in the Ignace area.

These capabilities and capacities we need to build with our people, our employees and Council, as well as our supporting infrastructure and businesses.

Council is committed to a Strategic Capacity Plan that will guide the community through this new and exciting journey for the duration of the DGR Project understanding that the project will survive multiple generations of residents and many municipal councils. It is understood that this plan is a solid component of the agreement between Ignace and the Nuclear Waste Management Organization and as such will survive the life of the agreement between the two parties.

In 2024 Council has directed that a study be undertaken to move forward post The Multi Year Funding Agreement, a component of this study will be the development of the Strategic Capacity Plan.

Council is strongly committed to implementing the Strategic Capacity Plan and will use this plan to build the capabilities and capacities need to make Ignace and the DGR project a success that will bring success and sustainability to the community both in the present and for future generations.

Appendix D – Confidence in Transportation Package Performance

Title: Confidence in Transportation Package Performance		External Document No.: NWMO-0009-03 NWMO-0009-05	Revision: N/A
Company Name: Calian Nuclear			
NWMO Document No.: APM-REP-04220-0209	Revision: R000	NWMO P.O. No.: 2001542	
Date Submitted: 2023/09/13		Page: Approval Cover Sheet	

Confidence in Transportation Package Performance

NWMO Authorization

<Original signed by> 9/13/2023
Reviewed By: _____
G. Rodriguez
Associate Transportation Engineer

<Original signed by> 9/14/2023
Reviewed By: _____
U. Stahmer
Senior Transportation Engineer

<Original signed by> 9/14/2023
Reviewed By: _____
C. Burley
Director, Strategic Programs and Transportation (Social)

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Accepted by: _____
G. Cheema
Manager, Used Fuel Transportation

Associated with NWMO-STD-IM-0001, Standards for Controlled Documents

Associated with NWMO-PROC-IM-0002, Controlled Document Management

Confidence in Transportation Package Performance (Executive Summary)

Calian Nuclear Report NWMO-0009-05

Version 4.0

13 September 2023

Presented to:

Nuclear Waste Management Organization (NWMO)

22 St. Clair Avenue East, 4th Floor

Toronto, ON

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CALIAN

QUALITY ASSURANCE AND VERSION TRACKING

Authorization

Title		Confidence in Transportation Package Performance (Executive Summary)		
Document Number		NWMO-0009-05		
Ver.	Developed By	Reviewed By	Approved By	Date
1.0	H. Tahir	E. Easton R. Ross	A. Seguin	20-Jun-23
2.0	H. Tahir	E. Easton R. Ross	A. Seguin	14-Aug-23
3.0	H. Tahir	E. Easton R. Ross	A. Seguin	06-Sep-23
4.0	<Original signed by> C. Dionne	<Original signed by> A. Seguin	<Original signed by> A. Seguin	13-Sep-23

Release Tracking

Ver.	Action	By	Date
1.0	Release to the NWMO for review	C. Bellman	20-Jun-23
2.0	Release to the NWMO for acceptance	C. Bellman	14-Aug-23
3.0	Release final version to the NWMO	C. Bellman	06-Sep-23
4.0	Release with minor formatting fixes	<Original signed by> C. Bellman	13-Sep-23

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EXECUTIVE SUMMARY

1.1 Introduction

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel (UNF). Canada's plan is known as Adaptive Phased Management (APM). It consists of containing and isolating UNF in a deep geological repository (DGR) using a multiple barrier system in a robust host geology. A DGR is a system of tunnels and placement rooms constructed underground, several hundred metres below the surface within a stable rock formation. Canada's UNF is currently safely stored on an interim basis in licensed facilities at reactor sites in Ontario, Québec, and New Brunswick, as well as at AECL's (Atomic Energy of Canada Limited) nuclear research laboratories in Ontario and Manitoba.

NWMO is in the process of identifying a willing host community or region for the repository site with plans to select one community by 2024. The site selection process started in 2010, with 22 municipalities and Indigenous communities showing interest. NWMO has narrowed down the options through technical evaluations and engagement activities to ensure safety and community partnerships. Managing all of Canada's UNF in a single repository location will require the transport of UNF from these interim storage facilities to the centralized DGR location.

NWMO's responsibility includes designing and developing a transportation system for the safe and secure delivery of UNF from current interim storage locations to the deep geological repository. Current plans are to begin operations at the repository facility no sooner than the 2040s. The transport of UNF from the existing interim storage sites to the repository will commence once the facility is licensed and operational. NWMO is considering two transportation system options: an all-road option or an intermodal road/rail option to each potential host site. The transportation program is anticipated to take place over a period of approximately 45-50 years.

Community and Indigenous engagement activities conducted as part of the DGR siting process have determined that transportation safety is a topic of broad interest for Canadians and Indigenous peoples. Feedback from engagement activities has shown that there are opportunities to enhance NWMO's dialogue with the public about radioactive materials currently transported in Canada and internationally.

This Executive Summary summarizes the *Confidence in Transportation Package Performance* report [1] (hereafter referred to as the "report") which aims to provide insights into transportation regulations for radioactive materials, emphasizing the safety of people and the environment. The report discusses package design, regulatory requirements, and testing processes, with case studies and examples from countries with established transportation programs and those planning DGRs. The report also addresses frequently asked questions from NWMO's engagement activities.

1.2 Overview of Radioactive Materials Transportation Package Types and Requirements

Approximately one million packages containing radioactive materials are safely transported in Canada every year [10]. This includes sources used by industry, waste generated during power generation activities, and life-saving medical radioisotopes. The responsibility for ensuring the safe transport of radioactive material at the federal level is jointly shared between the Canadian Nuclear Safety Commission (CNSC) and Transport Canada. The International Atomic Energy Agency (IAEA) has published regulations for transporting radioactive materials – the *Regulations for the Safe Transport of Radioactive Material* (referred to as SSR-6 in this Executive Summary). Canada's *Packaging and Transport of Nuclear Substances Regulations, 2015* (referred to as PTNSR in this Executive Summary) are based on SSR-6. The PTNSR is primarily concerned with the health, safety and security of the public, and protection of the environment related to the transport of radioactive materials.

Transport Canada has adopted the *Transportation of Dangerous Goods Regulations* (referred to as TDGR in this Executive Summary). The TDGR is concerned with the transport of all classes of dangerous goods. The TDGR defines nine classes of dangerous goods based on hazards associated with the goods to be transported. UNF only falls under Class 7 – Radioactive Materials. The main hazard for Class 7 dangerous goods is the emission of ionizing radiation, which, in high doses, can affect the body's cells and disrupt other metabolic processes. However, packages for shipping radioactive materials are designed to protect the public and the environment from this radiation. Figure 1 shows the label for Class 7 – Radioactive Materials.



Figure 1: Class 7 TDG label

1.2.1 Radioactive Materials Transportation Safety Regulations



Figure 2: Used Fuel Transportation Package (UFTP)

Transportation safety regulations for radioactive materials follow a graded approach, imposing stricter requirements as the hazards of the materials increase. There are limits on the radioactive contents inside a package that determine the package type required. UNF in the NWMO's transportation program will be shipped using Type B packages. An example Type B package, the Used Fuel Transportation Package (UFTP), is shown in Figure 2. Additional information on other package types is provided in Section 2.3.2 of the report.

The graded approach for transportation packages is illustrated in Figure 3. Figure 3 also lists the

requirements for each package type. Note that the requirements are cumulative as the hazard increases – this means that Type B packages are subject to general requirements as well as the requirements for routine, normal, and accident conditions of transport. Packages containing fissile material, uranium hexafluoride, or that are to be shipped by air (Type C packages) are subject to additional requirements. In general, package safety standards are less strict for materials with lower activity concentrations, become stricter for larger quantities that are readily dispersible, and add additional safety requirements for fissile material. The World Nuclear Transport Institute offers a comparison between Type A and Type B packages as an example of the graded approach [12]. A more detailed description of the graded approach is illustrated in Table D-4 in Appendix D of the report.

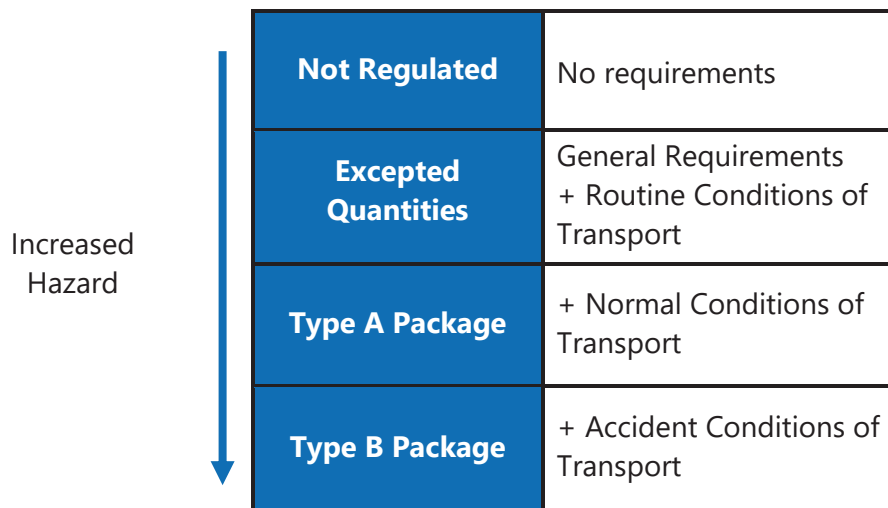


Figure 3: Graded approach for transportation packages and applicable requirements

1.2.2 Controls for Transport

Controls for transport are implemented to ensure transportation of UNF packages comply with the regulations. This includes ensuring that radioactive materials were properly classified and the appropriate package type for transport was selected. These controls are described in more detail in Section 2.4 of the report.

Limits are enforced for radioactive contamination on accessible surfaces of transport packages. Packages are leak-tested to ensure the constructed package meets the performance specifications of the design. Radiation dose limits are in place on the amount of radiation the public and nuclear energy workers may receive.

Shipment communications, such as shipping papers, the labelling and marking of packages, placarding, and paneling of vehicles, are key methods for communicating the presence and potential hazard of radioactive materials to workers, emergency responders, and the public. Before a shipment, these systems communicate the potential hazards of the material to be shipped and ensure the correct procedures are applied when selecting and preparing the package.

In the event of an accident, the placards facilitate the identification of the dangerous good being carried. This allows emergency responders to take actions to protect public health and safety. Figure 4 shows the UFTP with a dangerous goods category label and information plate.

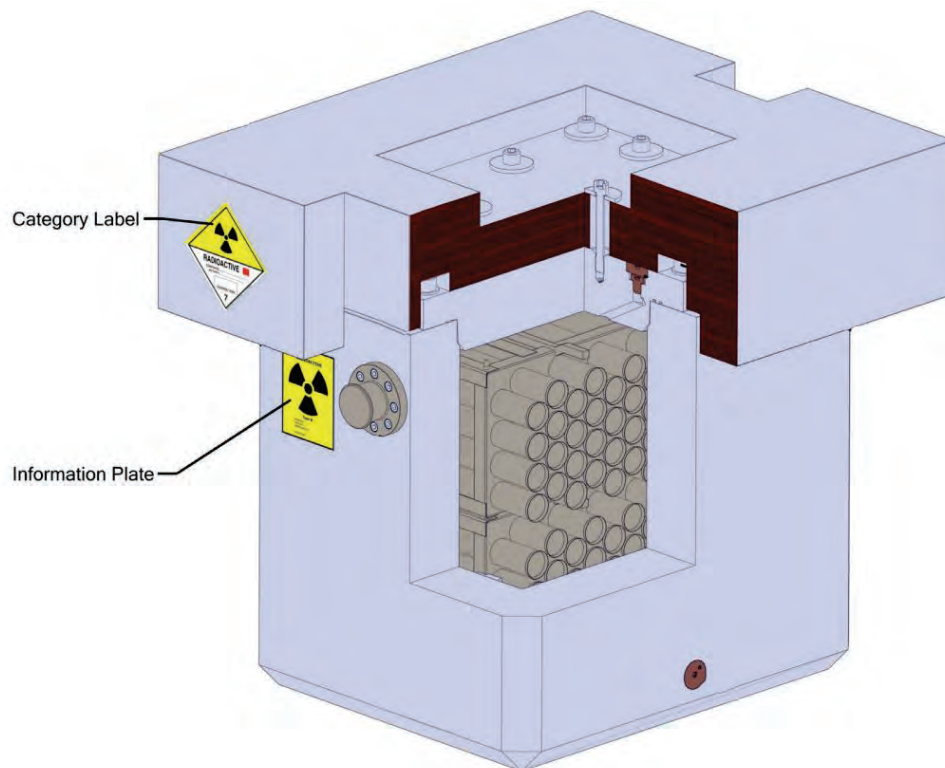


Figure 4: Dangerous good category label and information plate on the UFTP

1.3 The Design of Type B Packages to Withstand Severe Accident Conditions

The IAEA has established a classification system for packages used to transport radioactive materials that is based on a graded approach. The Type B classification signifies that the package is intended for materials with higher levels of radioactivity, such as used nuclear fuel.

The approval of Type B packages is based on a rigorous testing and certification process to ensure their compliance with internationally accepted safety standards. Package certification in Canada is conducted by the CNSC. The test conditions described in the safety standards are used to demonstrate that a package can provide adequate radiation shielding and containment of radioactive materials under normal conditions of transport and the conditions expected in a severe accident.

The Type B package types being considered for use by the NWMO transportation program are the UFTP, the Dry Storage Container Transportation Package (DSC-TP), and the Basket Transportation Package (BTP). Information on these three packages is provided in Section 3.4 of

the report. The BTP is excluded from the assessments contained in the report as its design is currently under development. The applicable regulatory tests for Type B packages are described in this subsection and illustrated in Figure 5.

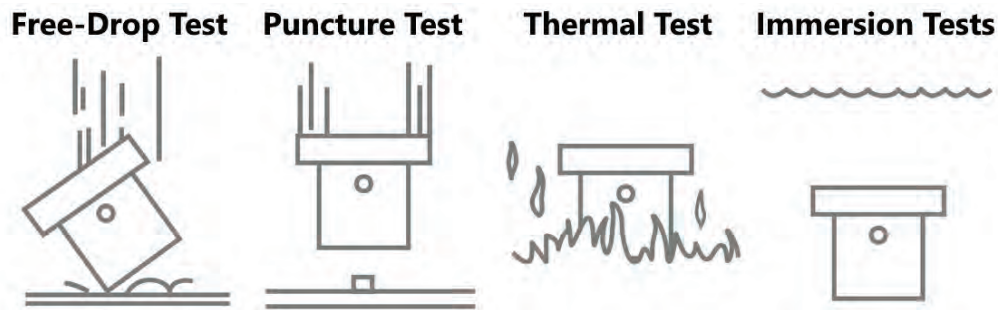


Figure 5: Regulatory tests applicable to Type B packages

To prove a package's performance under severe accidents conditions, the regulations require that a package design be evaluated for four major tests. The tests are designed to bound the conditions that are normally associated with severe accidents. The four tests are:

Free-Drop Test: The Free-Drop Test is conducted by dropping a package from a height of 9 meters onto a flat, unyielding surface in an orientation which will inflict maximum damage. This test measures the package's integrity in an accident by assessing the damage caused by an impact with an unyielding surface.

Puncture Test: The Puncture Test is conducted by dropping a package from a height of 1 m onto a rigid, perpendicularly mounted 15 cm diameter steel bar, at least 20 cm long, attached to an unyielding surface. This test must use the same package as used in the Free-Drop Test and must be in the orientation that has the package suffering the maximum damage. The Puncture Test simulates what would happen in a collision with an object, such as exposed rebar, guardrail, or a jutting piece of rail track.

Thermal Test: After the Free-Drop and Puncture tests, the same package undergoes a fully engulfing fire. The fire must maintain an average temperature of 800°C for a minimum of 30 minutes, starting from an ambient temperature of 38°C. The fire's heat flux must be equivalent to that of a hydrocarbon fuel-air fire with specific parameters. The fire test conditions mimic real-life fire scenarios.

Immersion Tests: There are two immersion tests applicable to the Type B packages being considered as part of NWMO's transportation program. Both tests may be conducted with a different package than the Free-Drop, Puncture, and Thermal tests.

- a. *Water Immersion Test:* The package is subjected to an external water pressure of 150 kPa (equivalent to 15 m depth) for 8 hours, in the orientation that results in the most damage to the package. The test is used to assess the damage that a package could experience in

transport accidents that occur by water bodies near most bridges, roadways, and harbours, where 15 m is a reasonable estimate of water depth. The test ensures that the integrity of the package body and use of properly designed seals prevents the significant release of radioactive material in shallow waters.

- b. *Enhanced Water Immersion Test*: The package is subjected to an external water pressure of 2 MPa (equivalent to 200 m depth) for 1 hour without rupture of the containment system. This test was implemented to facilitate the recovery of large quantity radioactive material packages from the continental shelf should an accident occur during maritime shipping.

The regulations allow several methods to demonstrate that a package meets regulatory requirements. These include full-scale testing, scale models, mock-ups of specific parts of a package, calculations (analytical and computational methods) and reasoned arguments or a combination of these methods. The intent is to allow an applicant to use accepted engineering practices to evaluate a package design. Regardless of the method used, documentation should be sufficiently accurate and complete to allow an approving authority (e.g., Canadian Nuclear Safety Commission) to determine that all safety requirements have been met and all modes of failure considered. In practice, a package design for used fuel typically uses a combination of computer modeling, scale model testing and full-scale mock ups of package components.

The use of a particular method or combination of methods is left to the discretion of the approving authority who must make the ultimate decision that a used package design meets the safety regulations.

Additional information on package testing is provided in Section 3.3 and Appendix E of the report.

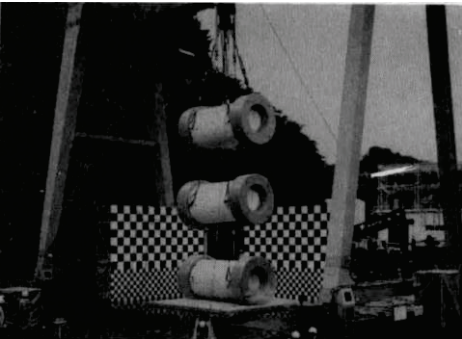
1.4 Demonstration Tests

This section explores some of the demonstration tests conducted over the last five decades to validate the effectiveness of IAEA package safety standards, and the performance of packages under accident conditions. Some of the most relevant demonstration tests to Canadian UNF transportation are summarized in Table 1.

Table 1: Most relevant demonstration tests to Canadian used nuclear fuel transportation

Image	Performing Organization	Description of the Test	Results Summary
United States (Section 4.2 in the report)			
	Sandia National Laboratories	A tractor-trailer carrying a 20.5 tonne lead shielded used fuel package was impacted against a rigid barrier at a velocity of 97 km/hr. The 626 tonne concrete barrier was backed by more than 1 580 tonnes of earth. This target was designed to be an unyielding surface. [32], [29]	While the tractor-trailer rig was completely demolished during the impact, the package itself suffered only superficial surface damage. The package was subsequently equipped with a new front impact limiter, was remounted on an identical shipping trailer attached to another tractor, and impacted at 135 km/hr. This time, some fuel pin buckling occurred; however, no cladding failure was detected.
	Sandia National Laboratories	A 109 tonne locomotive was crashed at a speed of 130 km/hr into a 23 tonne used fuel package mounted on a trailer attached to a conventional tractor at a simulated grade crossing. [32], [30]	The locomotive impacted the tractor-trailer rig broadside. The inside cavity of the package was not deformed although some of the fuel rods had bowed slightly, the assembly was otherwise undamaged. Leak testing after impact indicated a small leak in the head seal. However, had the package contained cooling water, as older package designs were designed to have, this leakage would have caused no risk to the public.

Image	Performing Organization	Description of the Test	Results Summary
	Sandia National Laboratories	A 136 tonne rail package shipping system was crashed into a massive concrete barrier at 129 km/hr. The shipping package itself weighed 68 tonnes. [32], [31]	The impact resulted in extensive damage to the railcar structure, but the damage to the concrete barrier was minimal and barrier deflection was negligible. The package body was not deformed except for minor deformations to the external cooling fins.
United Kingdom (Section 4.3 in the report)			
	Central Electricity Generating Board	This test simulated a severe rail accident involving a full-sized Magnox used fuel package and consisted of a 140 tonne Class 46 locomotive traveling at 160 km/hr colliding with a stationary 47 tonne Magnox package attached to a 13 tonne rail car. [33]	The package survived the test with minimal damage and during post-test examination, was found to have held its internal pressure to within 0.002 MPa of the 0.69 MPa to which it had been pressurised originally.
Germany (Section 4.4 in the report)			
	BAM	A fire test was performed with a 45 m ³ Liquefied Propane Gas (LPG) tank wagon, partially filled with 10 m ³ of pressurised liquid propane. A CASTOR THTR/AVR used fuel package was positioned above a fuel oil pool beside the propane tank to suffer maximum damage from the subsequent explosion. [34], [35]	Although the unprotected closure lid of the CASTOR package was exposed to fire and severely hit by tank wagon fragments, post-test investigations demonstrated that no loss of leak tightness occurred following the propane tank's explosion.

Image	Performing Organization	Description of the Test	Results Summary
	BAM	A 1:2 scale model of the TN 8/9 used fuel package certified to the IAEA transport regulations was dropped 200 m from a helicopter onto a 20x30 m concrete target consisting of a 60 cm layer of pit gravel and 40 cm layer of concrete reinforced by steel mats. [34], [35], [37]	While the outside of the package suffered superficial damage, there was no loss of integrity of containment components, and no leaks were detected following the test.
Japan (Section 4.5 in the report)			
	CRIEPI	Two 9-metre drop tests and a 1-metre puncture test were performed on a full-scale ductile cast iron (DCI) package. The first 9-metre drop included an artificial flaw of 20-mm in depth in the package. For each 9-metre test, the package was cooled down to less than -40°C (233K). During the 1-metre test, the DCI package was dropped horizontally onto a mild steel pin. [38], [39]	Sufficient fracture toughness data of full-scale DCI package bodies was obtained for quality assurance and to evaluate brittle failure. With the 1-meter test no penetration occurred, confirming the integrity against brittle failure with strain measurements. During the 9-metre tests, no crack propagation was observed from the artificial flaws.
	CRIEPI	Drop tests on DCI packages with no impact limiters were conducted in three different drop orientations, i.e., vertical, horizontal, and oblique with drop heights of 1.5 m, 7.5 m, and 17 m. [40]	The structural integrity of the packages without impact limiters was maintained against drop accidents at the tested heights.
	CRIEPI	In addition to the 15 m and 200 m immersion tests, packages designed for high-level waste (HLW) were immersed in 3 000 m of water for an hour. [40]	The maximum strain in the package body was within an elastic range and no rupture was observed during the test. No leakage was detected at any sealing boundary during the immersion test and no reduction in the sealing characteristics was observed.

1.5 Real-World Accident Reconstructions

An important tool in addressing the safety of used fuel shipments is the use of accident reconstructions to predict the performance of used fuel packages and transport systems under severe real-world accident conditions. Table 2 summarizes real-world accident reconstructions selected for discussion in the report. In all scenarios, had these accidents involved used fuel transportation packages, the packages would have survived the accidents and met regulatory requirements for containment and dose rate limits, demonstrating the robustness of the regulatory framework.

Table 2: Real-world accident reconstructions selected for discussion in the report

Description of the Accident	Accident Reconstruction	Results Summary
Baltimore Tunnel Fire (Section 5.2.1 in the report)		
On July 18, 2001, a freight train carrying non-nuclear dangerous goods derailed and caught fire in Baltimore, Maryland. The most severe part of the fire in the Howard Street tunnel lasted approximately 3 hours, while less severe fires continued for over 3 hours. Firefighters confirmed that the last tank car was no longer burning about 12 hours after the fire started. [44], [43], [45], [46]	The reconstruction was done to determine the thermal conditions and to analyze the potential effects of those conditions on three different Type B package designs certified to transport UNF. A detailed fire analysis was performed to determine the temperatures reached by the tunnel air, wall, floor and ceiling during the accident. The temperatures were used to model the performance of the three used fuel packages.	The study concluded that larger transportation packages would sustain only minor damage in a fire similar to the Baltimore tunnel incident. This is due to their thermal inertia and compliance with regulations. Although the likelihood of a release is low, any potential releases would be minimal due to factors, such as tight clearances, low-pressure differentials, and the settling of CRUD particles ¹ . The analysis shows that none of the package designs would exceed regulatory dose rate limits or result in significant releases or direct radiation in the fire scenario.
Caldecott Tunnel Fire (Section 5.2.2 in the report)		
In the Caldecott Tunnel accident on April 7, 1982, a tanker truck carrying gasoline overturned and caught fire. The fire lasted approximately 2.7 hours, with the intensely hot gasoline-fueled portion estimated to have lasted about 40 minutes. Firefighters entered the tunnel about 46 minutes after the fire started to search for survivors and approach the location of the tanker truck. [48], [47], [49]	The reconstruction was done to assess the fire's thermal conditions and potential effects on Type B truck packages used for transporting nuclear fuel. It used temperature predictions from National Institute of Standards and Technology's (NIST) to model its response to the fire.	The evaluation indicated that a severe tunnel fire, like the Caldecott Tunnel fire, would not result in the release of UNF particles or fission products from a shipping package. The design analyzed for the scenario did not reach temperatures that could cause fuel cladding rupture, ensuring that radioactive material would remain contained within the package and the fuel rods.

Description of the Accident	Accident Reconstruction	Results Summary
MacArthur Maze Fire (Section 5.2.3 in the report)		
On April 29, 2007, a tanker truck carrying gasoline caught fire on the MacArthur Maze interchange in Oakland, California. The intense heat weakened the steel girders of the roadway above, causing two spans of the elevated roadway to collapse onto the freeway below. A surveillance video from a nearby wastewater treatment plant captured the fire's progression. The first span sagged and collapsed at around 17 minutes, while the second span descended slowly and partially collapsed after about 37 minutes. The fire continued to burn intensely for about 102 minutes until the fuel was fully consumed. [50], [51]	The reconstruction was done to assess the fire's impact on the applicable truck package for transporting UNF. The accident, which involved a severe and prolonged fire causing the collapse of roadway segments, was chosen due to its unique structural consequences as the fire caused the overhead roadway segments to collapse. The study used fire modeling and physical examination of samples to define a bounding scenario of a fully engulfing pool fire at 1 100°C before the collapse and a less severe fire at 900°C afterward. Thermal and structural analyses showed that the package could withstand the fire and the loads imposed by the collapsing roadway segments.	The analysis shows that the package, in the event of the MacArthur Maze fire scenario, would not exceed regulatory dose rate limits for accident conditions, despite the expected loss of neutron shielding. The gamma shielding in the stainless-steel package body remains effective even at higher temperatures. While there is potential for radioactive material to escape due to seal loss and fuel rod rupture, the lid closure bolts prevent significant release. The estimated maximum release for this scenario is below the prescribed limit, ensuring that public health and safety would not be at risk.
Newhall Pass Tunnel Fire (Section 5.2.4 in the report)		
The Newhall Pass Tunnel accident involved a chain reaction traffic collision and fire in California. It affected 33 commercial tractor-trailer rigs and one passenger vehicle on the southbound US Interstate 5 truck route. The fire started near the tunnel exit and quickly spread, engulfing the entire tunnel. The fire destroyed all 24 trapped tractor-trailer rigs, which were carrying foodstuffs and not hazardous materials. The severe tunnel fire lasted for an estimated duration of 2 to 5 hours. [53], [52]	The reconstruction was done to assess the impact of the fire on a used fuel truck package. The accident was chosen for its prolonged fire duration and varied fire exposure scenarios due to multiple vehicles involved. A bounding fire scenario was defined based on fire modeling and physical examination of on-site material samples. Five specific fire modeling cases were used to encompass the range of possible fire conditions.	The potential radiation dose rates and package integrity of the packages were assessed in this fire scenario. The analysis showed that the package would not exceed regulatory dose rate limits despite the loss of neutron shielding, as it is already accounted for in the approval process. The gamma shielding of the package was expected to remain intact and functional. However, the study noted that the package could experience seal degradation in this severe accident scenario, potentially leading to a small release, approximately one quarter of the quantity permitted by regulations, and would not pose a risk to public health and safety.

Notes:

1. CRUD is a colloquial term used to denote corrosion products (e.g., rust particles) that adhere to the outside of used fuel rods that become radioactive when exposed to radiation.

1.6 Real-World Canadian Transport Accidents

An analysis of historical Canadian highway and rail accidents (from 1979 to 2022) was performed to identify relevant severe accidents and determine the impact those types of accidents could have on the highway and rail transport of used nuclear fuel. A list of severe accidents was compiled based on the presence of significant physical impacts (i.e., collisions and explosions), long-duration fires, release of dangerous goods, fatalities and injuries, and major property damage. None of the accidents listed involved the shipment of used fuel, or the transport or release of radioactive material.

Four representative historical accidents were chosen to examine how a shipment of used fuel might have fared during each accident. The results are summarized in Table 3 and described in greater detail in appendices G – M in the report.

Table 3: Real-world Canadian transport accidents selected for discussion in the report

Accident	Description	Predicted Outcome
Mississauga Train Derailment and Explosion – November 15, 1979	A freight train carrying hazardous materials derailed and caught fire in the middle of the town. The train was carrying a variety of chemicals, including propane, styrene, and chlorine, among others. The fire resulted in several explosions and an evacuation.	None of the forces (impact, puncture and explosion), or the fire that occurred in the Mississauga train derailment would be sufficient to either breach the package wall or severely damage the welded closure area of a DSC-TP.
Hinton Rail Collision – February 8, 1986	A westbound freight train and an eastbound passenger train collided head-on on a single-track section of the Canadian National Railway (CN) mainline. The collision resulted in the deaths of 23 people, including three crew members on the freight train, and 20 passengers on the passenger train. A fire was caused by fuel leaking from locomotives.	Neither the impact or puncture force that occurred in the Hinton train collision and derailment would be sufficient to either breach the package wall or severely damage the welded closure area of a DSC-TP. The Hinton collision resulted in a localized diesel fire that would not have seriously impacted a Type B package. There were no explosions. It is predicted that no release of radioactive material or increase in external radiation would have occurred under the conditions actually experienced in the Hinton collision.
Lac Mégantic Derailment and Explosion – July 6, 2013	A freight train carrying crude oil derailed causing fires and explosions resulting in the deaths of 47 people and the destruction of much of the town's downtown area.	None of the forces (impact, puncture and explosion), or the fire that occurred in the Lac Mégantic Derailment and Explosion train derailment would be sufficient to either breach the package wall or severely damage the welded closure area of a DSC-TP.

Accident	Description	Predicted Outcome
James Snow Parkway Accident – March 24, 1986	A gasoline tanker truck carrying 51 000 liters of gasoline collided with a flatbed truck under a highway overpass. The tanker exploded. The resulting fire caused concrete to burn away, exposing the inner steel reinforcing cables.	Neither the impact or puncture force that occurred in the James Snow collision would be sufficient to either breach the package wall or severely damage the package sealing area of a UFTP. A small release could be possible for a UFTP if the package seal operating temperature and fuel rupture temperature are exceeded.

Section 6 of the report also reviews transport practices and design features which could be employed to lessen the chances of a severe accident occurring or to mitigate possible impacts. These include the use of dedicated trains, enhanced safety standards for rail cars, providing escorts for truck shipments and employing advanced train instrumentation for early detection of conditions that lead to train derailments.

1.7 International Experience Transporting Used Nuclear Fuel and High-Level Waste

For more than sixty years, radioactive materials have been transported globally, adhering to a stringent regulatory regime established by the IAEA. The implementation of these regulations has resulted in an impressive safety record in that there has never been a transport incident that resulted in significant radiological harm to people or the environment. The World Nuclear Association currently estimates that about 15 million packages of radioactive material are transported around the world each year. Additional estimates show that since 1961, when the IAEA's safe transport regulations were first issued, it is likely that over one billion nuclear material consignments have been safely completed [60].

In 2016, the U.S. Department of Energy (DOE) published *A Historical Review of the Safe Transport of Spent Nuclear Fuel* which is considered the most extensive effort to describe the worldwide record on the transport of UNF. In summary, the report estimated that at least 25 400 shipments of UNF were made worldwide, but that number could potentially be more than 44 400. A significant finding from the report is that all of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported.

1.7.1 Countries with Strong Used Fuel Transportation Programs

Non-defense UNF transportation programs are designed to support a nation's nuclear energy program and its chosen methods for treating, storing, and disposing of UNF. Some countries, like Japan, France and the United Kingdom, opt for recycling their UNF through a closed-end system where the transportation program must safely handle UNF being transported for reprocessing, the reprocessed fuel, and the radioactive by-products of reprocessing (High Level Waste, or HLW).

The NWMO transportation program, on the other hand, supports an open-end system for the CANDU fuel used in Canada's nuclear energy program and research at the Canadian Nuclear Laboratories (CNL). The fuel passes through the reactor once, is subsequently cooled in pools, stored temporarily, and eventually transported to a permanent geological disposal site. As the UNF ages for several decades after leaving the reactor, it becomes cooler and less radioactive. Key country's employing the open-end system for used fuel include Finland (Posiva Oy), Switzerland (NAGRA), Sweden (SKB), and the United States (U.S. Department of Energy).

1.7.2 Key Country Transportation Plans

Table 4 summarizes the status of each key country's transportation program and plans. The information is based on publicly available sources about transportation modes, conveyances, contents being transported, number of shipments anticipated, distances, extent/scope of transportation systems and challenges.

Table 4: Summary of key country transportation plans and UNF management programs [62]

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
Canada Nuclear Waste Management Organization (NWMO)	The site selection process is expected to be completed by 2024.	No	No	Road and rail are being considered.	Anticipate construction beginning in 2033, operations planned to begin in the 2040s.
Finland Posiva Oy	The Finnish Government approved construction of the Onkalo DGR in 2015.	No	No	Road and sea are the most likely choices.	DGR facility is expected to be operational in 2023. Disposal activities expected to begin in 2025.
France National Agency for Radioactive Waste Management (Andra)	A site near the village of Bure was selected in 2006.	Yes - reprocessed used fuel from France, Japan, Germany, Belgium, Switzerland, Italy, Spain and the Netherlands.	No	Preference is for rail to DGR.	Plan to begin the pilot phase in 2025–2027 timeframe.
Japan Nuclear Waste Management Organization of Japan (NUMO)	NUMO plans to complete the site selection process before 2030.	Yes - Reprocessing takes place at the Tokai Reprocessing Plant. Rokkasho Reprocessing Plant expected to be completed in 2023.	Yes - at the Recyclable-Fuel Storage Center.	No decision has been made.	Plan to start repository operations before 2040.

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
Sweden Swedish Nuclear Fuel & Waste Management (SKB)	A site in the municipality of Östhammar was selected in 2009.	No	Yes – at Clab near Oskarshamn Nuclear Power Plant.	Plan to transport UNF to Östhammar using a specially designed ship, the Sigrid.	SKB expects to start repository operations sometime in the 2030s.
Switzerland National Cooperative for the Disposal of Radioactive Waste (NAGRA)	NAGRA plans to submit a license application by 2024 and be operational in 2060.	Yes - commercial UNF was reprocessed in France and the UK HLW has been returned to Switzerland.	Yes - the central storage facility (ZZL) near Beznau Nuclear Power Plant.	Road and rail transport options are being considered.	Repository operations are expected to start in 2060.
United Kingdom Nuclear Waste Services (NWS)	NWS expects it will take 5 to 20 years to complete the site selection process.	Reprocessing at Sellafield took place from 1964 to 2022.	Yes - at Sellafield. The facility will be used for UNF and HLW until the 2070s.	Road, rail and sea transport options are being considered.	No decision has been made.
United States U.S Department of Energy (DOE)	The Yucca Mountain site was approved for development by Congress in 2002. Congress has not funded construction.	U.S. does not currently reprocess commercial UNF.	Two Consolidated Interim Storage Facility licenses have been approved by NRC. Neither are accepting UNF at this time.	Considering road and rail. No rail transportation is available to the Yucca Mountain site or from many reactor sites.	No decision has been made.

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Confidence in Transportation Package Performance

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GLOSSARY

Acronyms and Initialisms

AAR	American Association of Railroads
AGR	Advanced Gas-cooled Reactor
ANSI	American National Standards Institute
BAM	Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung)
BLEVE	Boiling Liquid Expanding Vapour Explosion
BTP	Basket Transportation Package
BWR	Boiling Water Reactor
CANDU	Canada Deuterium Uranium
CEGB	Central Electricity Generating Board
CFD	Computational Fluid Dynamics
CN	Canadian National Railway
CNA	Canadian Nuclear Association
CNSC	Canadian Nuclear Safety Commission
CPR	Canadian Pacific Railway
CRIEPI	Central Research Institute of Electric Power Industry
DCI	Ductile Cast Iron
DDF	Deep Disposal Facility
DG	Dangerous Goods
DGR	Deep Geological Repository
DOE	Department of Energy (U.S.)
DOT	Department of Transportation (U.S.)
DRS	Direct Rail Services
DSC	Dry Storage Container
DSC-TP	Dry Storage Container Transportation Package
DU	Depleted Uranium
EBS	Engineered-Barrier System
EM	Environmental Management (U.S. DOE Office)
FEA	Finite Element Analysis
GDF	Geological Disposal Facility
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate-Level Waste
IMO	International Maritime Organization
INS	International Nuclear Services
IP	Industrial Package
ISO	International Organization for Standardization
JAEA	Japan Atomic Energy Agency

JNFL	Japan Nuclear Fuel Limited
LL-LLW	Long-Lived Intermediate Level Waste
LLW	Low-Level Waste
LPG	Liquified Propane Gas
LSA	Low Specific Activity
MOX	Mixed Oxide
MPC	Multi-Purpose Canister
NAS	National Academy of Sciences (U.S.)
NDA	National Decommissioning Authority (UK)
NFT	Nuclear Fuel Transport Co, Ltd.
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration (U.S. DOE)
NPP	Nuclear Power Plant
NRA	Nuclear Regulation Authority (Japan)
NRC	Nuclear Regulatory Commission
NTS	Nuclear Transport Solutions (UK)
NTSB	National Transportation Safety Board (U.S.)
NUHOMS	NUTECH HORIZONTAL MODULAR Storage
NUMO	Nuclear Waste Management Organization of Japan
NWMO	Nuclear Waste Management Organization
NWS	Nuclear Waste Services (UK)
OCRWM	Office of Civilian Radioactive Waste Management (U.S. DOE Office)
PATRAM	The International Symposium on the Packaging and Transportation of Radioactive Materials
PNNL	Pacific Northwest National Laboratories
PTNSR	Packaging and Transport of Nuclear Substances Regulations
PWR	Pressurised Water Reactor
REMM	Radiation Emergency Medical Management
RWM	Radioactive Waste Management Limited
SCO	Surface Contaminated Object
SFRO	Spent Fuel Reprocessing Organisation (Japan)
STUK	Radiation and Nuclear Safety Authority (Finland)
TC	Transport Canada
TDG	Transport of Dangerous Goods
TDGR	Transportation of Dangerous Goods Regulations
UFTP	Used Fuel Transportation Package
UNF	Used Nuclear Fuel
VCD	Vapor Cloud Detonation

Definitions

Accident Reconstruction: Analysis of an accident after it has occurred to determine more information and gather data. (See Section 5)

Contamination: Radioactive material that is deposited in water or air, or on the surfaces of structures, areas, objects, or people. (Based on [1])

Deep Geological Repository (DGR): A network of underground tunnels and rooms that safely stores, contains and isolates used nuclear fuel over the long term. (Based on [2])

Demonstration Test: Planned test that represents a viable transportation accident and where the test parameters (e.g., temperature, drop height, velocity) are controlled to allow measurement of the output results. (See Section 5)

Dose: When radiation (see definition below) penetrates or passes through an object or a living organism (such as a person), some of the energy of the radiation may be absorbed. This absorbed energy is called radiation *dose*. Dose is the physical effect, or consequence, of the radiation.

High-Level Radioactive Waste: Used nuclear fuel whose owners have declared it as radioactive waste and/or which generates significant heat through radioactive decay. Radiation shielding and long-term isolation is required. (Based on [3])

Interim Storage Facility: Location for safe management of used nuclear fuel over the short or intermediate term.

International Atomic Energy Agency (IAEA): An international organization that promotes the safe, secure and peaceful use of nuclear technologies. (Based on [4])

Package: Packaging with its radioactive contents, as presented for transport. [5]

Packaging: One or more receptacles and its components necessary to perform safety functions when transporting radioactive contents. (Based on [6])

Radiation: Energy emitted by a radioactive material. Materials that emit radiation are called radiation *sources*. Radiation sources can be in many forms (solid, dust, gas, liquid). Radiation can occur from natural sources (called *background radiation*) such the earth's crust and minerals found in soil or bedrock as well as artificial sources such as smoke detectors or televisions. Exposure to radiation from these natural and artificial sources occurs on a daily basis. *Ionizing* radiation is radiation that has enough energy to free electrons from atoms or molecules, which can result in a higher risk to human health. (Based on [7])

Radionuclide: A material (with an unstable atomic nucleus) that produces radiation. (Based on [8])

Special Form Radioactive Material: Either an indispersible solid (meaning that it cannot break up, scatter in different directions, or dissipate) or a sealed capsule.

Transportation Package: The complete product of the packing operation - meaning the *packaging* (what stores the contents during transport) and the contents prepared for transport. (Based on [6])

Used Nuclear Fuel (or Spent Nuclear Fuel): Used fuel assemblies removed from a reactor after irradiation and treated as waste. Also called irradiated nuclear fuel or spent fuel in many references used throughout this report. Note: In Canada, *irradiated nuclear fuel* or *used nuclear fuel* is a more accurate term for *spent fuel* (a term used internationally and in some Canadian reports with the same meaning in this definition, to align with international agreements and conventions), because discharged fuel is considered a waste material even when it is not fully spent. (Based on [8])

1. INTRODUCTION

1.1 Background

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. Canada's plan is known as Adaptive Phased Management (APM). It consists of containing and isolating used nuclear fuel in a deep geological repository (DGR) using a multiple barrier system in a robust host geology.

A DGR is a system of underground tunnels and storage rooms for used nuclear fuel containers. It is constructed underground several hundred metres below the surface of a stable rock formation (at depths between 250 m and 1000 m for mined repositories). Isolation of the used fuel is provided by a combination of engineered and natural barriers (rock, salt, clay) and no obligation to actively maintain the facility is passed on to future generations. Figure 1-1 and Figure 1-2 depict the Engineered-Barrier System (EBS) designed by the NWMO specifically to manage used CANDU fuel in a DGR and the conceptual design of the site layout as proposed by the NWMO.

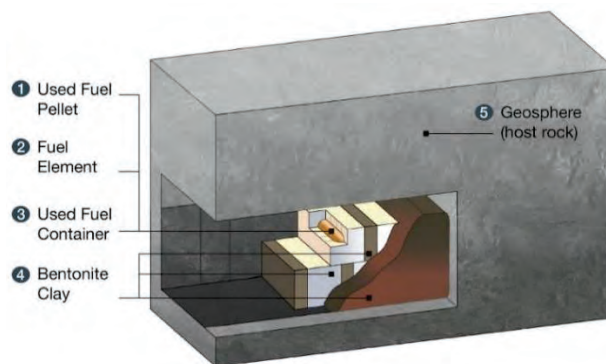


Figure 1-1: Engineered-Barrier System (EBS)

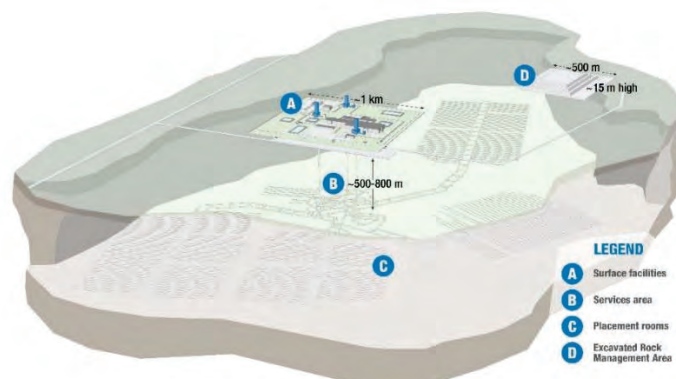


Figure 1-2: Conceptual Design of Deep Geological Repository Site

NWMO is in the process of identifying a willing host community or region for the repository site with plans to select one community by 2024. The site selection process has been underway since 2010. The process started with 22 municipalities and Indigenous communities expressing interest in learning more and exploring their potential to host the project. NWMO has gradually narrowed the focus to two remaining areas through technical site evaluations and social engagement activities to assess overall safety and the potential of the communities to build partnerships.

NWMO is currently engaging with communities and interested parties, including First Nations and Métis communities in the area. The Wabigoon Lake Ojibway Nation-Ignace area in Northwestern Ontario and the Saugeen Ojibway Nation-South Bruce area in Southern Ontario are considered potential host areas for the project. Figure 1-3 includes a map that shows the locations of the interim storage facilities as well as the two potential host communities.

Canada's used nuclear fuel is currently safely stored on an interim basis in licensed facilities at reactor sites in Ontario, Québec, and New Brunswick, as well as at AECL's (Atomic Energy of Canada Limited) nuclear research laboratories in Ontario and Manitoba. Managing all of Canada's used nuclear fuel in a single repository location will require the transport of used nuclear fuel from these interim storage facilities to the centralized DGR location. Figure 1-3 provides a visual overview of the interim storage site locations, alongside potential repository host communities.



Figure 1-3: Interim storage facilities and potential DGR siting areas across Canada

NWMO's responsibility includes designing and developing a transportation system for the safe and secure delivery of used nuclear fuel from current interim storage locations to the deep geological repository. Current plans are to begin operations at the repository facility no sooner

than the 2040s. Once the facility is licensed and operational, the transport of used nuclear fuel from the existing interim storage sites to the repository will commence.

NWMO is considering two transportation system options which include: (1) an all-road option; and (2) a road/rail option to each potential host site. The transportation program is expected to take place over a period of approximately 45-50 years.

Community and Indigenous engagement activities conducted as part of the DGR siting process have determined that transportation safety is a topic of broad interest for Canadians and Indigenous peoples. Engagement activities have demonstrated that while general information about the regulatory framework for transportation and the transportation package's ability to withstand severe accident conditions is available, people have many additional questions about the severity of the required tests and how the package would perform in real-world accident conditions. Feedback from engagement activities has also shown that there are opportunities to enhance NWMO's dialogue with the public about radioactive materials currently transported in Canada and internationally.

1.2 Scope and Objective

The safe and secure transportation of radioactive materials is an important part of the nuclear energy industry. It is crucial to make sure that materials like used nuclear fuel are transported safely and securely so that people and the environment are protected. The United Nations (UN) Model Regulations [9] serve as a basis for harmonizing international and domestic dangerous goods transport regulations and are reviewed and updated every two years. Regulations for the safe transport of radioactive materials are developed by the International Atomic Energy Agency (IAEA), a UN organization, and are also reviewed and updated regularly. The IAEA regulations are submitted to the Transport of Dangerous Goods (TDG) Sub-Committee of the UN for incorporation into the Model Regulations. In turn, the Model Regulations and the IAEA transport safety regulations are voluntarily adopted by regional or national regulatory authorities, including the Canadian Nuclear Safety Commission and Transport Canada [5]. These regulations are designed to make sure that transportation packages can ensure the safety of people and the environment during credible, severe accidents.

The purpose of this report is to provide insight into the key aspects of the transportation regulations. The report describes how used nuclear fuel packages are designed, tested and certified using these stringent regulatory requirements to ensure the health and safety of people and the environment. The report also demonstrates the soundness of the regulatory design and testing regimen for transportation packages (with an emphasis on Type B packages - those which transport used nuclear fuel).

Over many decades, organizations and research institutions from around the world have contributed to a robust body of knowledge encompassing regulations, rigorous testing of packages, and evaluations of applicable accident scenarios associated with the transport of

radioactive material. This report aims to present portions of relevant historical reports and sources in a manner that more clearly showcases the safety of radioactive material transport and packages. In certain sections (i.e., demonstration tests (Section 3), accident reconstructions (Section 5)) this report presents findings as originally written to avoid misrepresenting the research and conclusions presented by their original authors. The report also showcases countries with well-established transportation programs and provides information on how countries with proposed deep geological repositories (DGRs) plan to transport their used nuclear fuel and high-level waste. Finally, this report provides answers to questions frequently asked during the NWMO's community and Indigenous engagement activities.

1.3 Structure

This report is organized according to the following structure:

Section 1: Introduction

Provides an introduction to the report as well as background and context.

Section 2: Overview of Radioactive Materials Transportation Package Types and Requirements

Provides an overview of the graded approach applied to transportation packages as well as the requirements for the various types of transportation packages.

Section 3: The Design of Type B Packages to Withstand Severe Accident Conditions

Describes the regulatory tests used to demonstrate that Type B packages can withstand severe accident conditions.

Section 4: Demonstration Tests

Outlines demonstration tests that were completed to demonstrate the survivability of transportation packages under conditions of severe accidents.

Section 5: Real-World Accident Reconstructions

Describes severe transportation accident reconstructions that have been analyzed to assess the performance of transportation packages.

Section 6: Real-World Canadian Transport Accidents

Describes severe Canadian transport accidents and provides a qualitative assessment of these accidents against regulatory tests.

Section 7: International Experience Transporting High-Level Waste

Provides an overview of the transport of used nuclear fuel and high-level waste (HLW) in countries with established transportation programs and their strategies for the management of used nuclear fuel transportation.

Section 8: Frequently Asked Questions

Provides answers to questions frequently asked during the NWMO's community and Indigenous engagement activities.

2. OVERVIEW OF RADIOACTIVE MATERIALS TRANSPORTATION PACKAGE TYPES AND REQUIREMENTS

2.1 Introduction

Approximately one million packages containing radioactive materials are safely transported in Canada every year [10]. This includes industrial sources, waste generated during power generation activities, and life-saving medical radioisotopes. The responsibility for ensuring the safe transport of radioactive material at the federal level is jointly shared by the Canadian Nuclear Safety Commission (CNSC) and Transport Canada. As described in Section 2.3, the International Atomic Energy Agency (IAEA) has put in place regulations for transporting radioactive materials – the *Regulations for the Safe Transport of Radioactive Material* [6] (referred to as SSR-6 in this report).

Based on SSR-6, the CNSC has developed the *Packaging and Transport of Nuclear Substances Regulations, 2015* (referred to as PTNSR in this report). The PTNSR is primarily concerned with the health, safety and security of the public, and protection of the environment related to the special characteristics of radioactive material.

Transport Canada has developed the *Transportation of Dangerous Goods Regulations* [11] (referred to as TDGR in this report). The TDGR regulates the transport of all classes of dangerous goods – see Section 2.2 for an overview of the various types of dangerous goods. The framework for transport regulations in Canada as applicable to radioactive materials is presented in Figure 2-1. Note that the *Provincial/Territorial Dangerous Goods Transportation Acts* are not discussed in this report since federal regulations have primacy for radioactive materials.

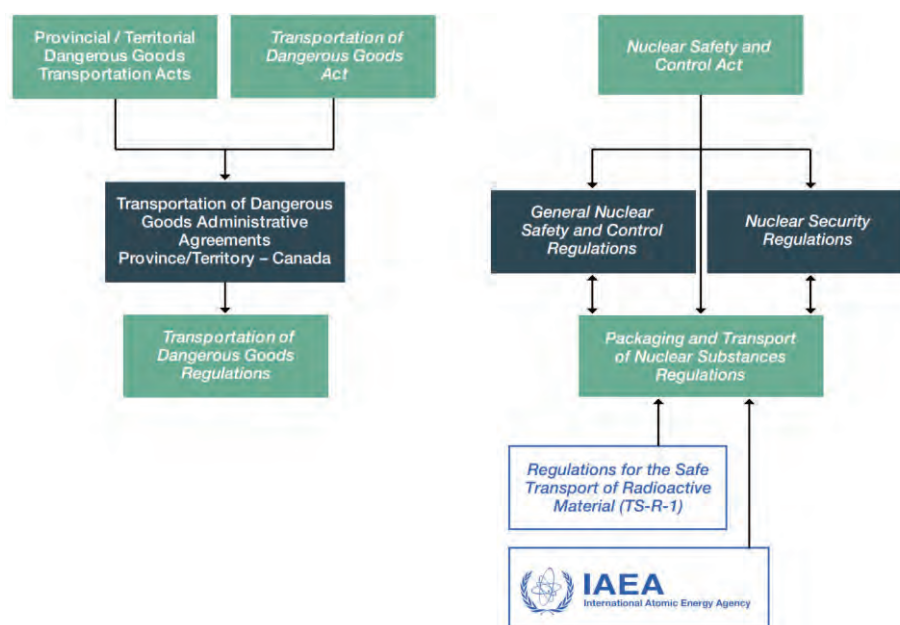


Figure 2-1: Canadian regulatory framework for transportation of radioactive materials

2.2 Classes of Dangerous Goods

The TDGR defines nine classes of dangerous goods, as shown in Figure 2-2. These classes of dangerous goods are based on hazard types associated with the goods to be transported. Note that the safety marks in Figure 2-2 are examples of safety marks for each class but do not represent all possible options.

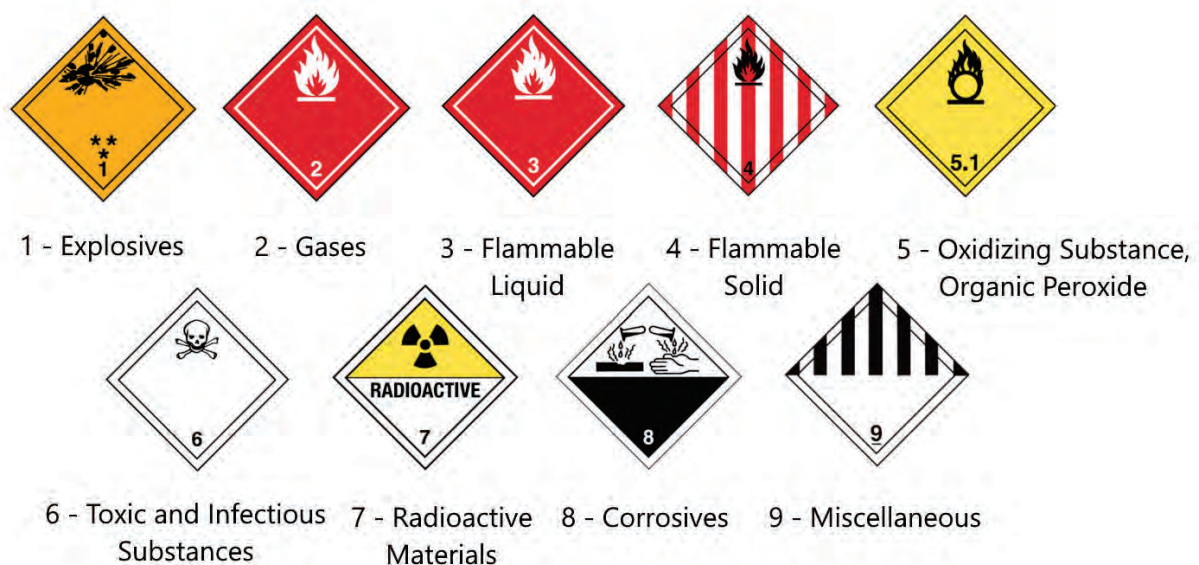


Figure 2-2: Nine classes of dangerous goods in Canada's TDGR

Used nuclear fuel typically only falls under Class 7 – Radioactive Materials. However, Class 7 also includes a broader range of radioactive material than used nuclear fuel. Class 7 dangerous goods include any nuclear substance with an activity above the exemption quantity defined in the PTNSR. This includes goods such as radioactive ores (from mining), medical isotopes, some medical equipment and parts, and industrial testing sources.

The main hazard for Class 7 dangerous goods is the emission of ionizing radiation, which, in high doses, can affect the body's cells and disrupt other metabolic processes. Packages for shipping radioactive materials are designed to protect humans from this radiation. Appendix A provides some of the most common types of ionizing radiation emitted by Class 7 radioactive materials.

As noted in Section 2.1, approximately one million packages containing radioactive materials are safely transported in Canada every year. The transportation of radioactive materials is essential to medical, industrial and research applications such as medical diagnosis and therapy, food irradiation, crop research, industrial gauges, and non-destructive testing.

This report will refer interchangeably to *Class 7 dangerous goods* and *radioactive materials*.

2.3 Radioactive Materials Transportation Safety Regulations

As demonstrated in Figure 2-1 in Section 2.1, radioactive materials are subject to the requirements of the CNSC's PTNSR in addition to Transport Canada's Transportation of Dangerous Goods Regulations and Act. The requirements in the PTNSR are structured based on a graded approach – this means that more stringent or strict requirements are applied as the hazards of the materials contained in the package increases. The hazards of different radioactive materials depend on such parameters as quantity, concentration, and dispersibility.

The CNSC issues certificates for the packaging and transport of nuclear substances, as stipulated in the PTNSR. Note that when the CNSC certifies (approves) a shipping package design, it is actually approving the package design for a set of specific contents. This means that use of a package is only valid for the contents that have been specifically analyzed and approved in the certificate. Any significant changes in package design or in contents requires additional approval from the issuing authority.

The inclusion and evaluation of specific package contents as a condition of the approval is important in the design of used nuclear fuel packages. The design and required performance of the package is based on the physical and chemical properties of the contents (e.g., nature, form and activity). For packages certified to transport used nuclear fuel, important parameters to consider are fuel type, quantity, initial enrichment, burnup and cooling time.

2.3.1 Graded Approach

The transportation safety regulations for radioactive materials apply a graded approach. Package types are assigned based on parameters such as quantity (activity), concentration (specific activity), dispersibility (i.e., form) and the fissile nature of the radioactive material. Special requirements are added for shipping contents with high activities by air due to the increased dispersibility of a package's contents in severe air accidents. In general, package safety standards are less strict for materials with lower activity concentrations, become stricter for larger quantities of material that are readily dispersible, and add additional safety requirements for fissile material.

Used nuclear fuel that is planned to be transported as part of the NWMO's transportation program does not qualify as special form (non-dispersible) radioactive material and therefore, is referred to as normal form material. As such, detailed information on special form material is not included in this report.^{1,2}

¹ Special form is radioactive material that is encapsulated or an indispersible solid. Special form material cannot be inhaled in significant quantities if released during a severe accident. Qualification as special form material requires that the encapsulation itself must meet severe accident conditions. A sealed radioactive source used in radiography operations is a common example of a special form radioactive material.

² Normal form is radioactive material that is dispersible. While used fuel is "encapsulated" in sheathing, the sheathing is not qualified as special form.

The limit for the quantity of normal form radioactive material in terms of radioactivity is defined in the regulations as the A_2 value. The A_2 value reflects the maximum activity that can be transported in a Type A package. The A_2 limit is the basis used to select the type of package required and defines the design and testing requirements for that package.

An example of a graded approach in comparing Type A and Type B packages is as follows [12]:

- o **Type A package:** Type A packages are used for the transport of relatively small, but significant, quantities of radioactive material. Since it is assumed that this type of package theoretically could be damaged in a severe accident and that a portion of their contents may be released, the amount of radionuclides they can contain is limited by the IAEA Regulations (i.e., the A_2 value). In the event of a release, these limits ensure that the risks from external radiation or contamination are at a level which protects public health and safety.
- o **Type B package:** These packages must withstand the same normal transport conditions as Type A packages, but because their contents exceed the Type A limits or the A_2 value, it is necessary to specify additional resistance to release of radiation or radioactive material due to accidental damage. The concept is that this type of package must be capable of withstanding expected accident conditions without a release of radioactive material or an increase in radiation level which would endanger the general public and those involved in rescue or clean-up operations.

Additional context on the A_2 values is provided in Appendix B.

As the hazards associated with a transportation package increase, the graded approach is applied to the requirements applicable to that package. All radioactive materials are subject to general requirements.

The following severity levels are applied according to the package type:

- (a) Routine conditions of transport (incident free)
- (b) Normal conditions of transport (minor mishaps)
- (c) Accident conditions of transport

Appendix D includes detailed information on the regulatory requirements based on the conditions of transport listed above, as well as a more detailed view of the graded approach.

For normal form radioactive material, the A_2 value defines the content limits for a Type A package. Type A packages can only contain an amount of contents **less than or equal to the A_2 value**. If the contents are **above** the A_2 value, a Type B package is required. This graded approach to quantity limits in transportation packages is illustrated in Figure 2-3. Figure 2-3 also lists the requirements for each package type.

Note that the requirements are cumulative as the hazard increases – this means that Type B packages are subject to general requirements as well as the requirements for routine, normal and accident conditions of transport. Packages containing fissile material, uranium hexafluoride or that are to be shipped by air (Type C packages) are subject to additional requirements.

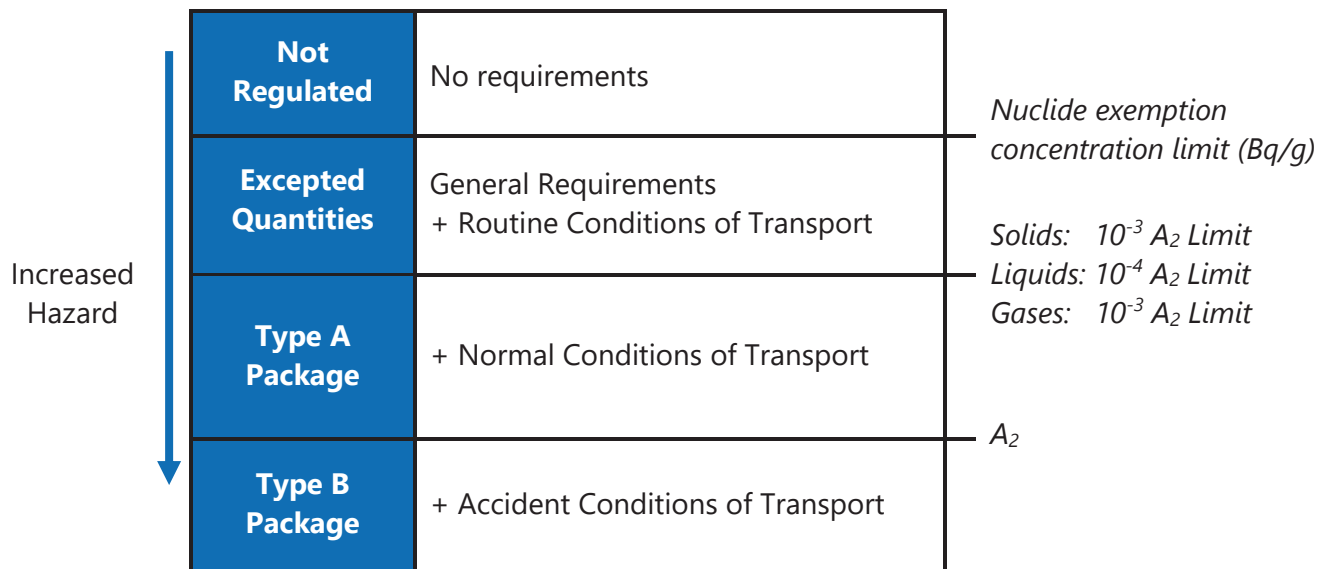


Figure 2-3: Graded approach based on quantity/activity (A_2) in transportation packages with normal form contents

2.3.2 Transportation Package Types

As discussed in previous sections, the requirements applicable to a transportation package depend on the transportation package type. The transportation package types described in the regulations are presented in Table 2-1.

Table 2-1: Transportation package types described in the regulations

Package Type	Description	Example Image [13] [14] [15] [16] [17]
Excepted Package	Excepted packages are utilized in the shipment of limited quantities of radioactive material that would pose a very low radiological hazards to members of the public. Examples of materials transported in excepted packages include consumer goods such as smoke detectors as well as empty used nuclear fuel packages.	
Industrial Package (For LSA and SCO – see Appendix C)	Industrial packages are used to transport certain low specific activity (LSA) materials and surface contaminated objects (SCOs). Most low-level radioactive waste is shipped in these packages. Examples of materials transported in industrial packages include uranium ores (from mining), contaminated dirt or contaminated laboratory clothing.	
Type A Package ($\leq A_2$)	Type A packages are intended to provide a safe means of transporting small quantities of radioactive material with higher concentrations of radioactivity than those shipped in industrial packaging. Examples of materials transported in Type A packages include radiopharmaceuticals (for medical use) and radioactive sources used in industrial applications. Unirradiated CANDU fuel is included in this category.	

Package Type	Description	Example Image [13] [14] [15] [16] [17]
Type B Package ($\geq A_2$)	Type B packages are designed to transport material with the highest levels of radioactivity. Examples of materials transported in Type B packages include high-level radioactive waste (such as used nuclear fuel) as well as materials with high concentrations of cesium and cobalt². Used CANDU fuel is included in this category.	
Type C Package (Very Large Quantities Transported by Air)	Type C packages are designed to transport material with the highest levels of radioactivity by aircraft. Examples of materials transported in Type C packages include plutonium and mixed oxide fuel.	

Notes:

1. Additional requirements are required for packages containing fissile material or uranium hexafluoride [5], [6].
2. Cesium and cobalt are frequently shipped for use in the medical industry. Cobalt-60 and Cesium-137 are commonly used for cancer treatment as well as medical device sterilization.

2.4 Controls for Transport

Controls for transport are implemented to ensure transportation of used nuclear fuel packages are in compliance with the regulations. This includes ensuring that radioactive materials were properly classified and the appropriate package type for transport was selected. Controls for transport deemed most relevant to the NWMO's transportation program for Type B packages are described in this section. Additional information on controls for transport is provided in Section V of SSR-6 [6] and the PTNSR [5].

2.4.1 Contamination and Package Leak Testing

Limits are applied to the amount of radioactive contamination on all normally accessible working surfaces of packages. The surface contamination limit is based on limiting the amount of radioactive material that can be removed from the package surface from routine activities to an amount that will not significantly affect public health and safety. Any package that has become contaminated above the regulatory limits during the transport of radioactive material is to be decontaminated as soon as possible by a qualified person and is not to be reused unless the contamination no longer exceeds the limits.

Prior to shipment, a Type B package must be leak tested to assure that it is properly sealed and meets the criteria for acceptable release.³ A helium leak test is a common method used to test whether a package meets the release requirement, because it is impractical to test the release of radioactive material directly. The small release rates required by the regulations result in extremely small clearances between the package body, the O-ring seals, and the lid, which would likely be plugged by any small particles. Using a helium leak test enables a package containment to be tested to leak tightness, defined as $1 \times 10^{-7} \text{ cm}^3/\text{s}$ [18]. This is approximately one teaspoon of gas every three years. Most used fuel packages are designed to be leak tight.

2.4.2 Dose Limits

Limits are in place on the amount of radiation the public and nuclear energy workers may receive. Canadian regulations draw upon the recommendations of the IAEA regulations and guides which follow the recommendations of the International Commission on Radiological Protection (ICRP). Both organizations comprise some of the world's leading scientists and other professionals in the field of radiation protection. As such, radiation dose limits are applied to the transportation of radioactive material. When assessing a package's integrity at an accident scene, radiation dose limits can also be used to determine if damage has occurred to the package (e.g., damage may have occurred if the radiation around the package is measured to be higher than the limits).

³ The acceptable release is defined in the regulations as a very small quantity, one-millionth of an A₂ per hour.

2.4.3 Shipment Communications

Shipment communications, such as shipping papers, the labelling and marking of packages and placarding and paneling of vehicles, are key methods for communicating the presence and potential hazard of radioactive materials to workers, emergency responders, and the public.

Before a shipment, these systems communicate the potential hazards of the material to be shipped and ensure correct procedures are adhered to when selecting and preparing the package.

During an accident, the placards facilitate the identification of the dangerous good being carried. This allows emergency responders to take actions to protect public health and safety. These actions are described in Transport Canada's *Emergency Response Guidebook: A Guidebook for First Responders* [19]. Pages 258 to 269 provide potential hazards, public safety information, and emergency response guidance for radioactive materials.

Figure 2-4 shows the Used Fuel Transportation Package (UFTP) (a Type B package – see Section 3 for more details) with a dangerous goods category label and information plate. Note that in a typical transportation arrangement by road, the UFTP would be covered by a weather barrier and as such, the visible shipment communications would be on the weather barrier.

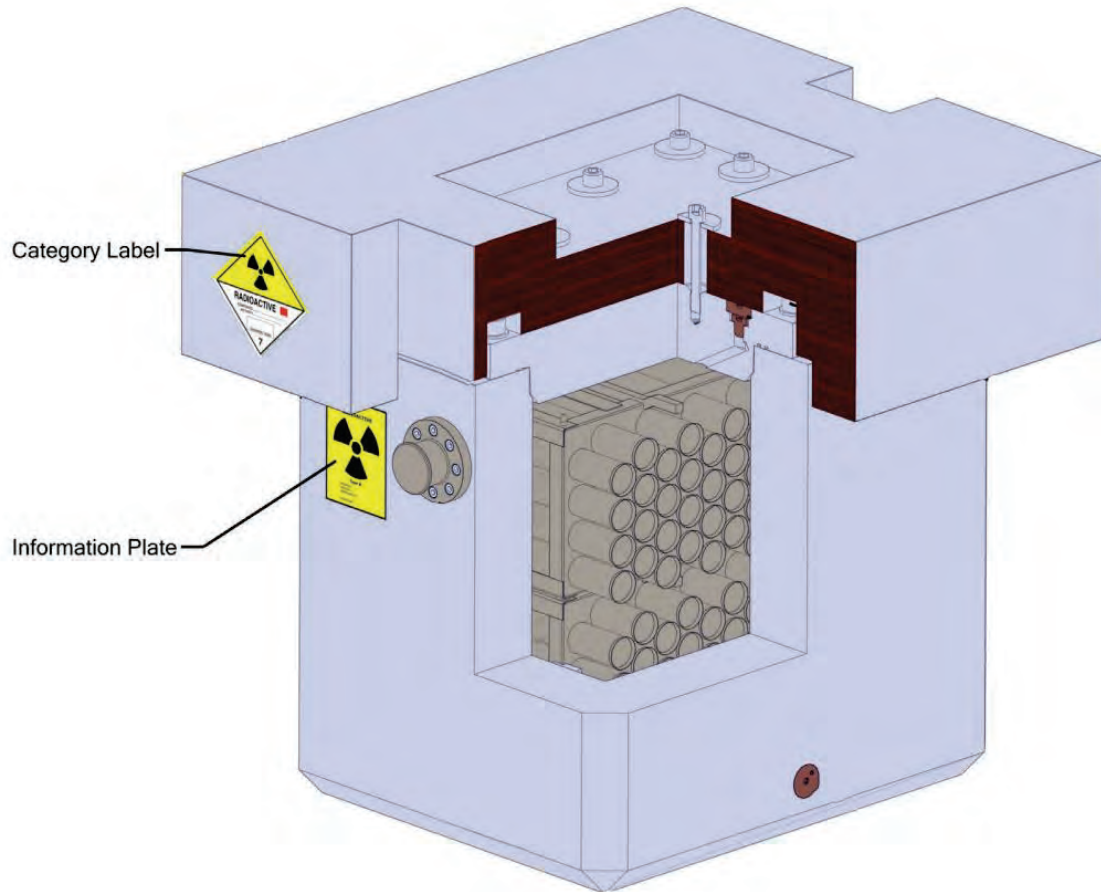


Figure 2-4: Dangerous good category label and information plate on the UFTP

3. DESIGN OF TYPE B PACKAGES TO WITHSTAND SEVERE ACCIDENT CONDITIONS

3.1 Introduction

The International Atomic Energy Agency's (IAEA) SSR-6 regulations and Canadian regulations (PTNSR) require that Type B package designs limit any loss of the radioactive contents and retain adequate shielding under normal and accident conditions of transport. Based on international research and technical input, the IAEA and national regulatory authorities established a set of accident test conditions which a Type B transportation package design must pass to be certified for use. These tests are defined in the IAEA's 'Regulations for the Safe Transport of Radioactive Material' requirements (SSR-6). As applicable to the Type B packages to be transported during the NWMO's transportation program these tests are as follows and illustrated in Figure 3-1.

1. **Free-Drop Test:** Dropping 9 m onto a flat, unyielding, horizontal surface, in the orientation that results in the package suffering the maximum damage. A description and rationale for this test is provided in Section 3.2.1.
2. **Puncture Test:** Dropping 1 m onto a rigidly, perpendicularly mounted 15 cm diameter steel bar at least 20 cm long. This test must use the same package as used in the *Free-Drop Test* and must be in the orientation that results in the package suffering the maximum damage. A description and rationale for this test is provided in Section 3.2.1.
3. **Thermal Test:** Fully engulfed in fire for 30 minutes at an average temperature of 800°C. This test must again use the same package as the *Free-Drop Test* and *Puncture Test*. A description and rationale for this test is provided in Section 3.2.2.
4. **Immersion Tests:** There are two immersion tests applicable to the Type B packages being considered as part of NWMO's transportation program. Both tests may be conducted with a different package than the *Free-Drop*, *Puncture*, and *Thermal* tests.
 - a. *Water Immersion Test:* Subjected to an external water pressure of 150 kPa (equivalent to 15 m depth) for 8 hours, in the orientation that results in the most damage to the package. A description and rationale for this test is provided in Section 3.2.3.
 - b. *Enhanced Water Immersion Test:* Subjected to an external water pressure of 2 MPa (equivalent to 200 m depth) for 1 hour without rupture of the containment system. A description and rationale for this test is provided in Section 3.2.4.

To gauge the cumulative effects on the package design, the first two tests are conducted in the sequence and in the orientation that results in the package suffering the maximum damage, followed by the thermal test on the same specimen. The regulations allow for computer-simulated as well as physical testing (using scale-model and full-scale model testing) to demonstrate the package's suitability for regulatory certification.

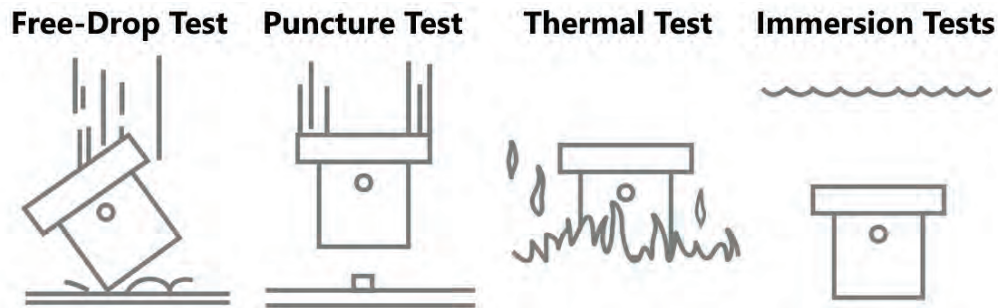


Figure 3-1: Regulatory tests in SSR-6 applicable to the NWMO's Type B packages [20]

3.2 Regulatory Tests for Type B Packages under Accident Conditions

As introduced in Section 3.1, the IAEA regulations describe a set of tests that Type B packages must undergo to demonstrate their ability to withstand accident conditions. The following subsections provide details on each of the tests applicable to Type B packages in the NWMO's transportation program. It also discusses the basis for their development and their bounding aspects when compared to real-world accident conditions.

The following information is summarized in subsequent sections:

- An overview of the regulatory test requirements for Type B packages under accident conditions is provided in Section 3.2.
- A description of the impact tests and rationale for the tests are provided in Section 3.2.1.
- A description of the thermal test and rationale for the test is provided in Section 3.2.2.
- A description and rationale of the water immersion and the enhanced water immersion tests are described in Section 3.2.3 and 3.2.4.
- A description of testing methods is provided in Section 3.3.
- The various packages being considered as part of NWMO's transportation program are described in Section 3.4.

Paragraphs 726-729 of SSR-6 describe the tests for demonstrating a package's ability to withstand accident conditions of transport as per the test acceptance criteria established in the IAEA regulations. Paragraph 730 of SSR-6 describes the *Enhanced Water Immersion Test* for Type B packages containing more than 10^5 A₂ (i.e., packages with a large amount of radioactive material – these include the packages being considered in the NWMO transportation program).

3.2.1 Impact Tests

The impact tests (an inclusive term for the *Free-Drop* and *Puncture* tests) consist of a series of two tests: *Free-Drop Test* and *Puncture Test*. The order of the two impact tests must ensure that the package will suffer the maximum damage during the thermal test that follows (see Section 3.2.2). Typically, this means that the *Puncture Test* follows the *Free-Drop Test*, depending on the package design. There is a third test called the *Crush Test*, described in Paragraph 727(c) of SSR-6 which is

not applicable to the transport packages being considered in the NWMO transportation program (in part due to their total weight).

Both impact tests must drop the package in the orientation that would result in the package suffering **maximum damage**. Typically, this means that the package is dropped on a corner in the *Free-Drop Test*, and near the seals, ports, or lid in the *Puncture Test*. Designers often perform several drops to ensure the most damaging sequence of orientations is identified.

The basis for both impact tests is described in Section 3.2.1.1, Section 3.2.1.2 and 3.2.1.3 explain why the *Free-Drop Test* and *Puncture Test*, respectively, bound the forces occurring during severe accidents.

3.2.1.1 Basis For the Impact Tests

The *Free-Drop Test* simulates an impact that is spread over a larger area, while the *Puncture Test* simulates what would happen in a collision with an object, such as exposed rebar, guardrail, or a jutting piece of rail track.

3.2.1.2 Why the Free-Drop Test Bounds the Forces Occurring During Severe Accidents

The *Free-Drop Test* measures the damage and the deformation of the package from an impact with an **unchanging surface**. An unchanging surface is rigid (e.g., metal plate and/or reinforced concrete pad) and is used for testing because it is stiffer than soil, soft rock, and some concrete structures which would be experienced in real-world accidents. Since the unchanging surface does not move or deform when hit by the package, all the energy (or damage) from the impact is imparted onto the package body. Most of this energy causes deformation to the package body. The concept of the unchanging surface is illustrated in Figure 3-2.

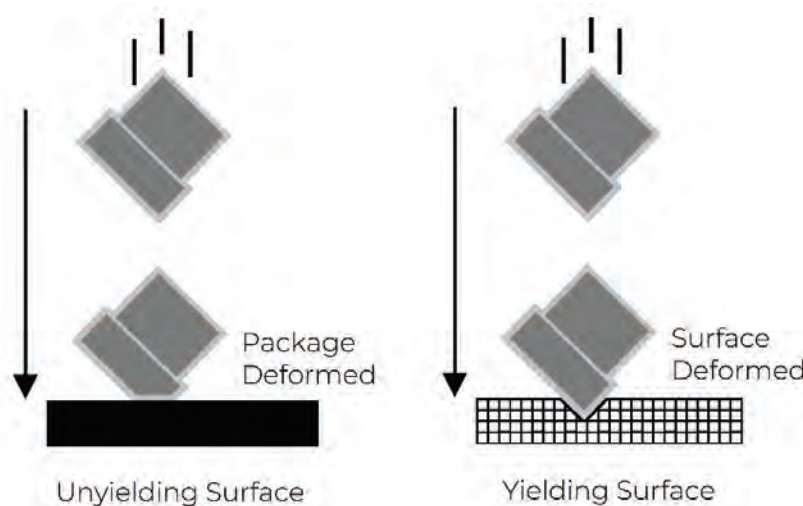


Figure 3-2: Deformation in an impact with an unyielding or yielding surface

In real-world scenarios, significant energy from the impact is transferred to the kinetic energies of the impacting vehicles, the package, the tie downs, and impact limiters [21]. The remaining energy is the amount available to be absorbed by the vehicle causing the collision (e.g., truck tractor, locomotive or ship), package trailer, or the package itself. Demonstration tests, such as Operation Smash Hit (see Section 4.3), have shown that the peak forces imparted to a package during a severe accident are in the order of 40% of those measured during a 9 m drop test onto an unyielding surface. [22]

The peak force on the package in the *Free-Drop Test* is larger than in real-world accident scenarios precisely because it is dropped on an unyielding surface. This means that, unlike in real-world accidents, the *Free-Drop Test* ensure that all impact energy is absorbed by the package rather than the object which the package strikes.

In addition, because the impact point is designated as the most damaging orientation for the package, the *Free-Drop Test* is bounding of the forces found even in very severe accidents. Furthermore, many package designs, including those being considered by in the NWMO transportation program, have impact limiters, which are non-rigid components designed to deform in an accident, thereby absorbing impact energy which would have otherwise been transferred to the package.

The *Free-Drop Test* bounds severe accidents because Type B transportation packages are designed to be much stiffer than objects they may collide with. The stiffness of the package is derived largely from the fact that a package is designed to absorb the total energy of a 9 m drop on to an unyielding surface with very little deformation to integral package components.

3.2.1.3 Why the Puncture Test Bounds the Forces Occurring During Severe Accidents

The *Puncture Test* assesses the vulnerability of packages to a through-wall puncture or lid deformation. Much like the *Free-Drop Test*, the *Puncture Test* is applied to the package in the orientation that results in the package suffering maximum damage. Additionally, the bar used during the test is rigidly, perpendicularly mounted to an unyielding surface.

As stated in Section 3.1, the regulatory tests are based on analyses of real-world accidents. Figure 3-3 and Figure 3-4 illustrate why puncture-type accidents are not a credible issue for Type B packages.

In Figure 3-3, data from the Association of American Railroads (AAR) shows the fraction of railroad tank cars that were punctured in an accident based on their shell thickness [23]. Railroad tank cars with a shell thickness greater than 1 in (2.5 cm – blue dashed line in Figure 3-3) were seldom seen to experience punctures. The two right-most red dots indicate that tank cars at these thicknesses (>1 in) had a fraction punctured of 0.00. The images of railroad tank cars on the right of Figure 3-3 are examples of tank cars susceptible to puncture. Accidents involving these tank cars are discussed in Section 5.

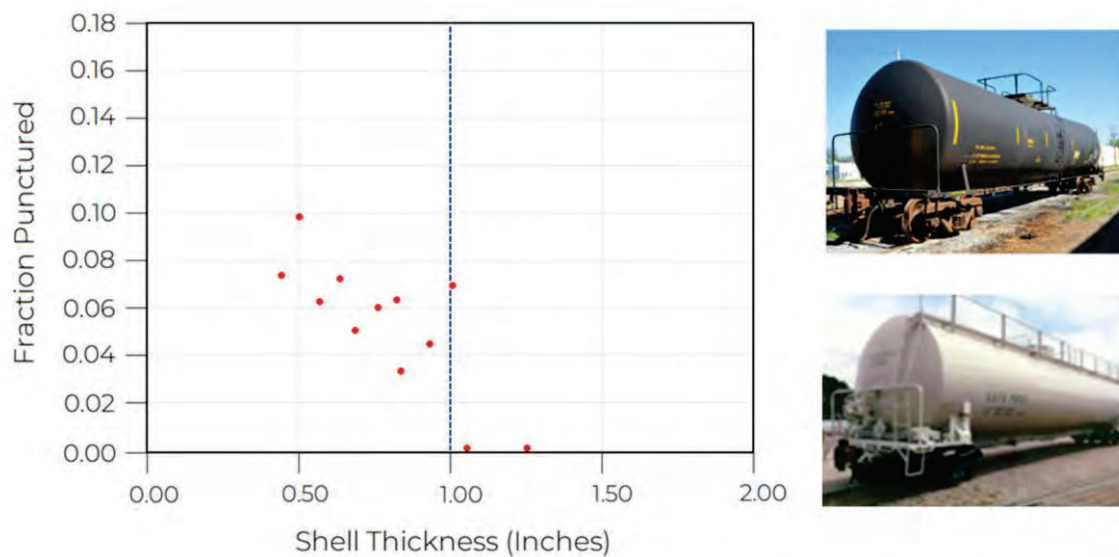


Figure 3-3: Fraction of railroad tank cars involved in puncture-type accidents based on shell thickness [23]

This data can be compared to the packages to be considered in the NWMO's transportation program. For example, the UFTP and Dry Storage Container Transportation Package (DSC-TP) have been designed and certified for use and are described in Section 3.4. The UFTP and DSC-TP have walls over 10 in (25 cm) thick. As such, failure due to puncture during an accident is highly improbable for these Type B packages.

Figure 3-4 shows these packages and their wall thicknesses superimposed on the same data featured in Figure 3-3. The x-axis has been scaled significantly to accommodate the thicknesses of these packages. The red dashed line again denotes a thickness of 1 in. The dark grey represents steel and the light grey represents concrete.

Unlike the Type B packages being considered as part of NWMO's transportation program, thin-walled and sandwich-walled packaging designs are susceptible to puncture loads, which can result in a loss of containment integrity, damage to the confinement system, or loss of thermal insulation. Even thick-walled designs may have weak points, such as closures of drain holes and valves. Puncture loads can occur during accidents when impact surfaces are uneven. To ensure safety, the 1 m drop test on a rigid bar was developed, with the drop height and punch geometry parameters being determined by engineering calculations.

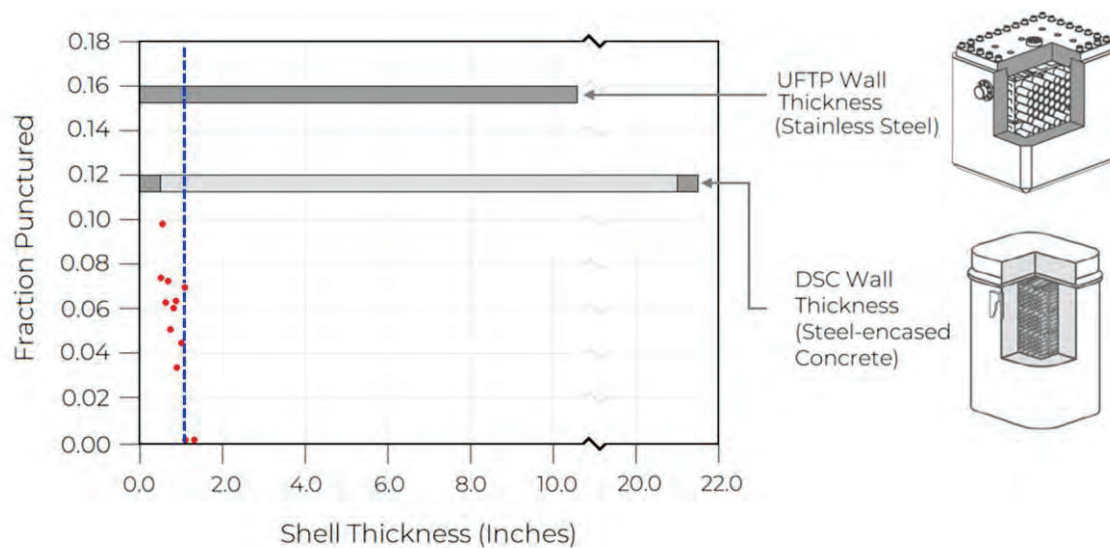


Figure 3-4: Fraction of railroad tank cars in puncture-type accidents with the thicknesses of the UFTP and DSC-TP overlaid

3.2.2 Thermal Test

Following the *Free-Drop* and *Puncture* tests, the same package used in these tests is subjected to a fully engulfing fire. The average fire temperature must reach 800°C for at least 30 minutes, with a starting ambient temperature of 38°C. The fire must provide a heat flux (rate of heat energy transferred through the surface) at least equivalent to that of a hydrocarbon fuel-air fire with specific fire parameters (see Paragraph 728 of SSR-6).

Following the fire, the package is exposed to an ambient temperature of 38°C and subject to solar insolation conditions (i.e., solar radiation on the package is simulated). The test considers the maximum rate of internal heat generation in the package and is only complete once the temperatures in the package are decreasing in all parts and/or are approaching initial steady state conditions. During and following the test, the package is not artificially cooled and if any combustion of package materials (i.e., wood impact limiter core) occur, it is permitted to proceed naturally. Note that CANDU fuel is not classified as explosive or flammable as it is solid high-density ceramic material encased in a durable zircaloy metal.

3.2.2.1 Basis For the Thermal Test

The *Thermal Test* assesses a package's performance to the effects of heat which could result from a typical fully engulfing hydrocarbon fuel-air fire. The test is based on a hydrocarbon fire as it is the most common type of fire in severe transportation accidents (i.e., petroleum or liquid natural gas).

The thermal test defines a number of physical parameters to use in evaluating the heat flux from a fire, such as fuel source, average flame temperature, duration, and location of package relative

to the fire, package absorptivity, and flame emissivity. The intent of the test is not to maximize each individual parameter, but rather to result in a heat flux that bounds that found in most severe transportation accidents.

3.2.2.2 Why the Thermal Test Bounds Fire Parameters Occurring During Severe Accidents

Type B packages are designed to withstand a fully engulfing fire for 30 minutes while maintaining critical functions, including limiting the release of radioactive material and protecting the public from external doses of radiation exceeding regulatory limits. The 800°C fire environment used in a certification test applies a heat flux similar to those found in real fires. The average turbulent flame temperature for hydrocarbon fuels in a moderate sized pool fire is approximately 800°C and is independent of the type of hydrocarbon fuel (Paragraph 728.3 of the IAEA's *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition)* (SSG-26) [24]. In the real-world, flammable liquids typically do not burn for more than 30 minutes in a single location because the fire exhausts its fuel supply (Paragraph 728.2 of SSG-26) [24].

In real accidents, the impact of a fire is determined by the orientation and location of the package in relation to the fire. In the *Thermal Test*, the fire is **fully engulfing** (Figure 3-5A) – this means that 100% of the package surface is exposed to the heat flux. In a real-world accident, one or more sides of the package would likely be protected by the transport vehicle involved in the accident, or the fire could act primarily on one side of the package (Figure 3-5B). If the package detached from the conveyance, the ground would act as a heat shield when compared to the fully engulfing fire required in the regulations (Figure 3-5A). The impact of the fire also rapidly decreases as the distance between the fire and package increases. These concepts are portrayed in Figure 3-5.

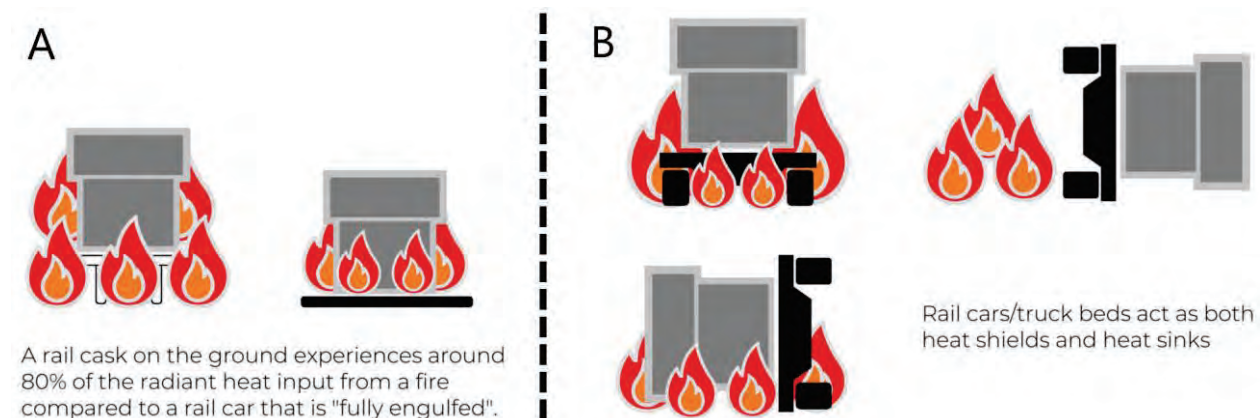


Figure 3-5: Comparison of the fire parameters in a real-world accident scenario versus a fully engulfing fire

Overall, the *Thermal Test* conditions simulate and bound the forces occurring in real-life scenarios as it creates a scenario which is fully engulfing and consistent. This subjects the package to thermal conditions which are equal to or greater than the thermal conditions occurring during a real-life accident.

3.2.3 Water Immersion Test

The *Water Immersion Test* requires that a package be immersed under 15 metres (50 feet) of water for at least eight hours in the attitude that will lead to the maximum damage. The test may be satisfied by immersion of the package, a pressure test on critical components combined with calculations, or by calculations for the whole package. For demonstration purposes, an external gauge pressure of at least 150 kPa can be used for the pressure test and calculations.

3.2.3.1 Basis For the Water Immersion Test

The *Water Immersion Test* is used to assess the damage that a package could experience in transport accidents that occur by water bodies near most bridges, roadways, and harbours which are less than 15 m deep. The main purpose of the test is to limit the potential consequences of a significant release of radioactive material near the coast or in a shallow body of water.

The test can be performed on a separate package from that used in *Free-Drop*, *Puncture* and *Thermal* tests, as the probability that this type of accident would involve significant impacts or fires is low [24]. The test duration (8 hours) was chosen to be long enough to allow the package to reach a steady state that is independent from processes that vary based on the speed at which they occur (rate-dependent processes) that might occur during immersion (e.g., the flooding of a package's exterior components such as the impact limiter).

3.2.3.2 Why the Water Immersion Test Bounds Pressures Occurring During Severe Accidents

The *Water Immersion Test* exerts a pressure of 150 kPa (15 metres of depth) on the package. The 15 m depth bounds the pressures occurring during severe accidents as the potential consequences of a significant release would be greatest near the coast or in a shallow body of water and 15 m is a reasonable estimate of water depth near most bridges, roadways or harbors.

This test ensures that the thick walls and lid of Type B packages are not susceptible to collapse or buckling at this pressure. In addition, design of the elastomer seals for packages would be required to withstand an external gauge pressure of 150 kPa. This test ensures that integrity of the package body (i.e., walls and lid) and use of properly designed seals prevents the significant release of radioactive material in shallow waters.

3.2.4 Enhanced Water Immersion Test

The *Enhanced Water Immersion Test* requires that packages with large radioactive contents (i.e., an activity of 10^5 A₂ or greater) be immersed under a head of water of at least 200 m for a period not less than one hour. Most Type B packages containing used fuel fall under this category. For demonstration purposes, an external gauge pressure of at least 2 MPa can be used for the

pressure test and calculations. The acceptance criterion for passing the test is that the package must not experience rupture of its containment system. This is different from the acceptance criteria of other accident condition tests (see previous sections).

3.2.4.1 *Basis For the Enhanced Water Immersion Test*

The *Enhanced Water Immersion Test* was implemented to facilitate the recovery of large quantity radioactive material packages from the continental shelf. The impact of the expected radioactive release into the environment would be acceptable at this depth, as shown by risk assessments [24]. Despite this, the test was imposed because recovery would be facilitated after the accident if the containment system was not ruptured, and thus only the retention of solids was considered necessary (Paragraph 660.3 of SSG-26) [24]. This test is conducted with a timeframe of 1 h as this is the time taken for the package to reach steady state under the pressures induced by the 200 m depth.

3.2.4.2 *Why the Enhanced Water Immersion Test Bounds Pressures Occurring During Severe Accidents*

The 200 m depth corresponds roughly to the depth of the continental shelf surrounding terrestrial continents, and where long-term radiological exposure to persons through the ocean food chain could occur. Although the *Enhanced Water Immersion Test* is primarily intended to facilitate recovery of large quantity packages, it requires that the package containment system remain unruptured in accidents involving a package sinking at particularly deep locations. This would allow the salvage of the package without endangering the health and safety of salvage workers. Assessments have been performed in the past that demonstrate that a package sinking to this depth would result in doses far less than regulatory limits [25]. Additional information is provided in *Consequences of Postulated Losses of LWR Spent Fuel and Plutonium Shipping Packages at Sea* [26].

3.3 Testing Methods

Testing to demonstrate Type B package design compliance with regulatory requirements can be performed using a combination of full-scale physical testing, scaled physical testing, computer modelling, and/or calculation. The following list (from IAEA SSR-6, Paragraph 701) presents the most common testing methods for Type B transportation packages.

- **Impact Tests (*Free-Drop Test* and *Puncture Test*):** The impact tests are often done by a combination of computer modelling and full-scale and/or scale-model testing. Full-scale physical tests and/or scale model physical tests (with consideration to scaling relationships – see Appendix E.1.2) are used to extract information about variables that are challenging to model computationally (e.g., O-rings, impact limiters).
- **Thermal Test:** Typically performed using full-scale physical tests or computer modelling (or a combination of both - see Appendix E.3). These tests are most often conducted using

computer modelling as full-scale models are costly and specialized facilities are required to conduct fire testing.

- **Immersion Tests:** Typically performed using computer modelling as it is the most cost effective and the data/variables can be obtained and controlled easily.

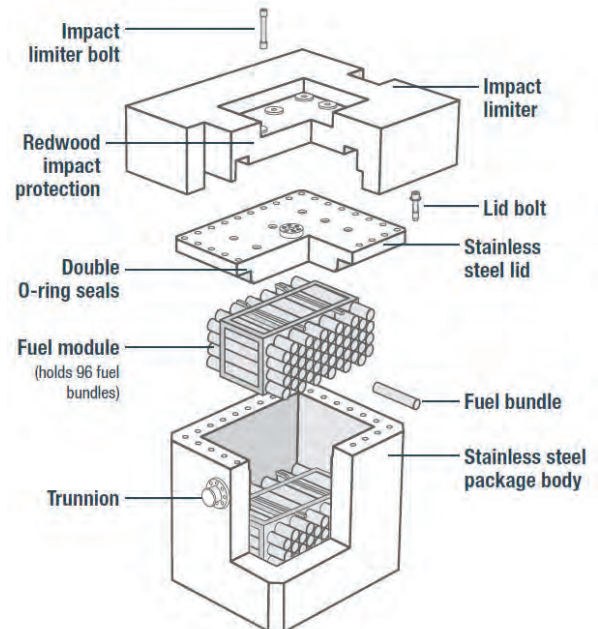
Note that this list does not mean that other methods cannot be used for these tests. Appendix E provides additional information on these various testing methods as well as the combined use of computer modelling and physical testing.

3.4 Design of UFTP, DSC-TP and BTP

Information on the UFTP and the DSC-TP is provided in this section from NWMO's Preliminary Transportation Plan [27]. Note that the Basket Transportation Package (BTP) design is excluded from assessments contained in this report as it is currently under development.

Used Fuel Transportation Package (UFTP)

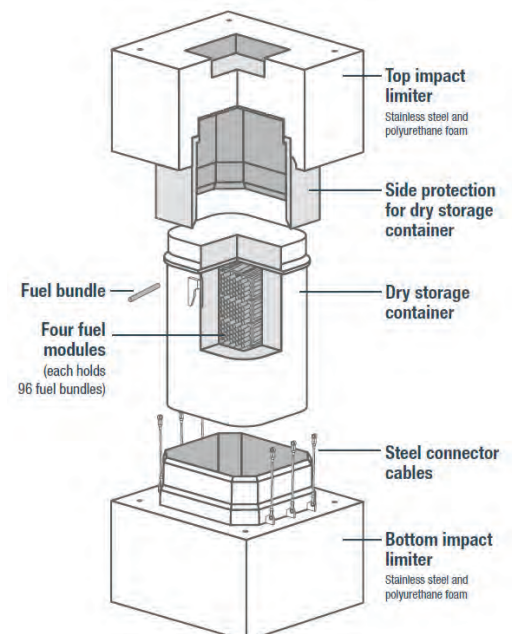
The UFTP consists of three main components: the body, lid and impact limiter. The body and lid are made of solid stainless steel with walls nearly 30 centimetres thick. The lid is attached to the body by 32 bolts. The impact limiter consists of a redwood core encased in a stainless steel skin. The stainless steel body and lid provide containment, shielding and impact resistance. The impact limiter is designed to protect the body and lid closure in the event of an accident. The reusable package can carry 192 used fuel bundles and weighs approximately 35 tonnes when loaded.



Dry Storage Container Transportation Package (DSC-TP)

Used nuclear fuel is currently stored on an interim basis in dry storage containers (DSCs) at Ontario Power Generation Waste Management Facilities. The DSC-TP consists of a DSC fitted with impact limiters on each end.

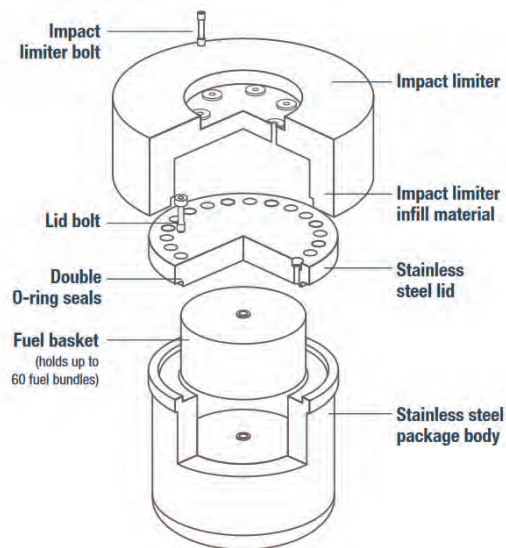
The DSC consists of a body and lid made of high-density concrete encased in a carbon steel skin. The DSC body and lid are welded closed after being filled with used fuel. The reusable impact limiters consist of stainless steel shells filled with rigid polyurethane foam. The impact limiters are fastened together using steel cables. The DSC provides containment and shielding, and the impact limiters are designed to protect the DSC in the event of an accident. The DSC can carry 384 used fuel bundles and weighs approximately 100 tonnes when loaded.



Basket Transportation Package (BTP)

The BTP is under development and designed to move used fuel that is currently stored in dry storage baskets. The BTP consists of the following main components: body, lid, and one or two impact limiter(s). The image on the right shows the BTP concept with one impact limiter. Impact limiters are designed to protect the BTP in the event of an accident. This reusable package can carry up to 120 used fuel bundles (two baskets) and is anticipated to weigh 28 tonnes when loaded.

As the BTP design is currently under development, it has been excluded from the assessments contained in this report.



4. DEMONSTRATION TESTS

4.1 Introduction

The goal of the International Atomic Energy Agency (IAEA) transportation safety regulations is to assure that Type B packages are designed, tested, and certified in such a way that people and the environment will be protected from the effects of ionizing radiation under any credible accident that might be encountered during transport [6]. This assurance is based on a combination of rigorous package safety requirements, the safety margins built into package designs, and the use of physical testing and analytical studies (e.g., computer modeling) to validate the performance of packages under severe accident conditions. As a result, Type B package use has seen decades' long records of shipping used fuel without a significant package failure both in Canada and abroad.

This section explores some of the demonstration tests conducted over the last five decades to validate the effectiveness of IAEA package safety standards, and the performance of packages under extreme accident conditions. The selected demonstration tests cover a wide range of topics, including severe transport impacts and fires, including the effects of explosions and airplane crashes on transport packages, the behavior of specific materials used in package fabrication, and the effectiveness of O-ring seals at low temperatures. These tests use dummy fuel to assess how fuel would interact with the package in these scenarios.

In large part, demonstration tests have been performed by countries which have significant experience in used fuel shipments. These countries include the United Kingdom, Germany, France, Japan and the United States. Some of the most relevant demonstration tests to Canadian used nuclear fuel transportation are summarized in the following subsections and listed in Table 4-1. References are cited in each section for a more detailed description and discussion of each test.

Table 4-1: Tests covered in this Section 4

Performing Organization	Package Tested	Type of Demonstration Test	Section
United States			
SANDIA National Laboratory	20.5-tonne Package	Truck – Rigid Barrier Collision (100 and 135 km/hr)	4.2
SANDIA National Laboratory	22.7-tonne Package	Rail – Truck Collision (130 km/hr)	4.2
SANDIA National Laboratory	68-tonne Package	Rail – Rigid Barrier Collision (130 km/hr)	4.2
United Kingdom			
Central Electricity Generating Board	MAGNOX	Stationary Package - Rail Collision (160 km/hr)	4.3
Germany			
BAM	CASTOR	Liquefied Propane Gas Explosion	4.4.1
BAM	TN 8/9	200-metre Drop Test	4.4.2
BAM	CASTOR	19.5-metre Drop Test	4.4.3
BAM	Elastomeric Seals	Behaviour at Low Temperature (-40°C)	4.4.4
BAM	TN 1300	Aircraft Crash (300 m/s)	4.4.5
Japan			
CRIEPI	Ductile Package Iron	9-metre Drop Test (-40°C)	4.5.1
CRIEPI	NFT-32B	5- and 17-metre Drop Tests without impact limiters	4.5.2
CRIEPI	HLW Package	3000-metre Immersion Test	4.5.3

4.2 Sandia National Laboratories – Crash Testing of Used Nuclear Fuel Shipping Systems

In the late 1970's, Sandia National Laboratories undertook a test program on behalf of the U.S. Department of Energy (DOE) to subject full-scale shipping packages and transport systems to severe accident conditions [28]. The program objectives were:

1. To assess and demonstrate the validity of current analytical and scale modelling techniques for predicting damage in severe accident conditions by comparing predicted results with the measured results from full-scale tests.
2. To gain quantitative knowledge of the response of full-scale shipping systems to extreme accident environments.

The results of the full-scale tests were not intended to validate regulatory standards. Three accident scenarios were chosen to represent severe road and railway accidents:

1. The crash of a tractor-trailer rig carrying a 20.5-tonne used fuel package traveling at velocities of 100 and 135 km/hr.
2. The high-speed impact of a 130 km/hr locomotive into a 22.7-tonne, truck mounted, used nuclear fuel package at a simulated grade crossing.
3. The crash of a railcar carrying a 68-tonne used nuclear fuel package into a massive concrete barrier at 130 km/hr, followed by exposure to a fire.

Each of the accident scenarios was evaluated in three separate phases:

Phase 1 – Structural Analysis

The basic dynamic response of the package system was determined analytically by a mathematical lumped parameter model using the one-dimensional SHOCK code. The HONDO code, a two-dimensional finite-element code, was used to calculate damage to the package shipping system using the impact velocity calculated by the SHOCK code.

Phase 2 – Scale Model Testing

A 1/8 scale model was used to predict the damage to the package and transport vehicle. The result of the 1/8 scale model test was compared to the results from the structural analysis.

Phase 3 – Full-Scale Testing

The results from the full-scale tests were compared to the results from both the structural analysis (i.e., SHOCK and HONDO) and the 1/8 scale model tests.

Description of the Tests

Truck – Rigid Barrier Collision [29]



Figure 4-1: Results of truck package impact into rigid barrier

A tractor-trailer (Figure 4-1) carrying a 20.5 tonne lead shielded used fuel package carrying an un-irradiated NS Savannah merchant ship reactor fuel assembly was impacted against a rigid barrier at a velocity of 97 km/hr [29]. The 626 tonne barrier was backed by more than 1 580 tonnes of earth and designed to be an unyielding surface with respect to the impact of the tractor-trailer rig (see Section 3.2.1.2 for a description of unyielding surfaces). While the tractor-trailer rig was completely demolished during the impact, the package itself suffered only superficial surface damage. The package was subsequently equipped with a new front impact limiter, remounted on an identical shipping trailer attached to a new tractor, and the test was repeated at a speed of 135 km/hr. In this test some fuel pin buckling occurred, which was similar to that experienced by a comparable fuel assembly in the regulatory drop tests. Despite this, no cladding failure was detected.

Rail – Truck Collision [30] [28]



Figure 4-2: Results of rail-truck collision

A 109 tonne locomotive (Figure 4-2) was impacted against a 22.7 tonne used fuel package mounted on a trailer attached to a conventional tractor at a simulated grade crossing [30]. The impact speed was 130 km/hr. The 109 tonne diesel--electric six axle locomotive was pushed up to speed by a sled containing six rockets fired in three stages. The locomotive impacted the tractor-trailer rig broadside. After crushing part of the trailer, the locomotive frame struck the package approximately 22 cm below the centerline of the package. Leak testing of the package after impact indicated a small leak in the head seal, when the package was pressurized. However, it was determined that, had the package contained cooling water, as older package designs were originally designed to do, this leakage would have caused essentially no risk to the public. Current package designs do not use cooling water as more efficient design methods have been adopted.

Rail – Rigid Barrier Collision [31]

Figure 4-3: Results of rail package impact into rigid barrier

A decommissioned 136 tonne rail package shipping system (shown in Figure 4-3), was crashed into an unyielding concrete barrier at 129 km/hr [31]. The shipping package itself weighed 68 tonnes. The package was fabricated from stainless steel with lead shielding. During the test the package was loaded with nine mock assemblies and one real unirradiated assembly. The impact resulted in extensive damage to the railcar structure. Damage to the rigid concrete barrier (which acted as an unyielding surface) was confirmed to be minimal. The package body was un-deformed except for minor deformations to the external cooling fins. No leakage was detected following the test.

Conclusions

The primary purpose of these tests was to demonstrate the validity of using analytical code tools (i.e., SHOCK and HONDO) and 1/8 scale modelling to predict the damage of a severe transportation accident as represented by the measured results from a full-scale test. The analytical and scale modelling techniques were used to predict the behavior of the full-scale system. The full-scale system responded as expected based on the predictions of the rigid body dynamics of the package during impact, and the resulting damage to the package was consistent with that predicted in pre-test analysis and scale modelling.

Preliminary calculations predicted how the package would impact the target. The second step in the analysis (the dynamic finite element model) predicted the deformation that would be sustained by the package. These two analytical techniques predicted the response of the vehicle and package in an extreme accident scenario.

The study concluded that both the analytical (i.e., SHOCK and HONDO codes) and scale modelling techniques could be used to accurately predict accident impacts and the vehicular and package damage in each of three accident scenarios used to represent extremely severe accident conditions. According to the study, *"The tests showed that, without exception the cask designs that were tested were not stressed in excess of the environments resulting from exposure of the designs to the regulatory standards [28]."* The study also demonstrated that the used fuel packages involved in the full-scale tests were capable of surviving the severe accidents modelled with little or no damage, and without loss of containment. See [29] [30] [31] [32] for additional information about these tests.

4.3 Central Electricity Generating Board - Operation Smash Hit (Railway)

Description of the Test



Figure 4-4: Resulting impact during Operation Smash Hit

In 1984, the Central Electricity Generating Board (CEGB) simulated a severe rail accident. The test involved a full-sized Magnox used fuel package on a railcar [33] being struck by an oncoming locomotive. To maximize the severity of the impact, the railcar carrying the Magnox package was turned on its side and orientated on a railway track so that the coupler of the oncoming train would directly strike the edge of the package lid at its most vulnerable location (Figure 4-4). The locomotive pulling three railcars and travelling at 160 km/h was then impacted into the Magnox package.

The results from the test were then compared to results obtained from a 9-metre drop test performed on an identical Magnox package. The comparison was performed to assess the forces on the package from the regulatory 9-metre drop against those experienced in the collision. To facilitate the comparison, the drop and crash tests were conducted so that the Magnox packages would be impacted at the same location.

Methodology

The CEGB set up a wide-ranging program of theoretical and experimental work to develop a detailed understanding of the way in which packages behave in severe transport accidents. At the time, there had been significant advances in computer analysis and in methods of physical testing and measurement. Given this, it was decided to use the latest available technology to study package accident behaviour from a more fundamental viewpoint than had been possible previously. Specific objectives of the project included an investigation into the validity of the use of scale models to represent full-size package behaviour, and a study of the relevance of the IAEA regulatory tests in relation to unlikely but credible transport accidents.

The project took place over a period of approximately four years and was based on a steady progression from the study of fundamental principles to the execution of a full-scale, 160 km/hr train crash. The main purpose of the work was to investigate the ways in which forces acting on a package resulted in permanent damage (i.e., package modelling studies) and to study the ways in which accidents generate forces on a package (i.e., real accident studies). The package test project

focused on the Magnox package, since this package was at the time the most widely used in the United Kingdom. In all, over a hundred tests on package components, model packages and other test pieces were conducted culminating in the drop testing of a full-sized Magnox package and a full-scale rail crash demonstration carried out in public view in July 1984.

Results

The package survived the test with minimal damage, and during post-test examination, was found to have held its internal pressure to within 0.002 MPa of the 0.69 MPa to which it had been pressurised originally. Measurements of transient and permanent deformations in the region of the lid/body interface confirmed that the impact experienced by the package was much less severe than that imposed upon it during the 9-metre regulatory drop onto a rigid target. The peak impact force produced by regulatory 9-meter drop test was 75 MN, while the rail crash test was found to have produced 29 MN - approximately 40% of the peak force produced by the regulatory test.

Conclusions

The following conclusions were drawn from the package test project:

- i. The use of scale models can be justified for estimating the impact performance of Magnox packages.
- ii. Mathematical (computer) models are an essential tool for developing a proper understanding of package impact behaviour. Properly validated models can be used in a predictive manner with a high degree of confidence.
- iii. The IAEA regulatory 9-metre drop test appears to cover credible severe accidents which can be expected to occur during transport. This is because there are added mitigation measures to minimize impact loads imposed on packages in real accident environments (e.g., impact limiters, tie down systems).

See [33] for additional information about this test.

4.4 Federal Institute for Materials Research and Testing (BAM)

The Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung or BAM) conducted a series of tests over the years to assess the safety of Type B package designs [34]. These tests included:

1. An explosion of a liquified gas tank wagon beside a CASTOR THTR/AVR spent fuel package [35].
2. A drop test of a 1:2 scale model of a Type B package (TN 8/9 model) from a height of 200 meters [35].

3. A drop test of a Type B package (CASTOR 1C) from a height of 19.5 m onto a 1 000 tonne unyielding target [35].
4. A gas leakage test of various sealing materials through thermal cycles between +20°C and -70°C [36].
5. Aircraft crash simulation tests to determine the effects of impact loads, building debris dropping onto standing packages, and the thermal effects of kerosene fires [37].

4.4.1 Liquified Propane Gas Explosion Beside CASTOR THTR/AVR Spent Fuel Package



Figure 4-5: Before fire and explosion test with CASTOR THTR/AVR package placed beside LPG tank wagon

On 27 April 1999, a fire test was performed by BAM with a 45 m³ Liquified Propane Gas (LPG) tank wagon, partially filled with 10 m³ of pressurised liquid propane. A CASTOR THTR/AVR package (22 450 kg package with 370 mm thick walls; double lid closure with inner 250 mm thick steel lid and outer 70 mm thick steel lid) was positioned above a fuel oil pool, and beside a propane tank to suffer maximum damage from the subsequent explosion (shown in Figure 4-5).



Figure 4-6: After explosion

The propane tank ruptured 17 min after the fuel oil fire ignition. This resulted in a boiling liquid expanding vapour explosion (BLEVE) with an expanding fire ball (100 m in diameter), heat radiation, and an explosive blast wave. Propane tank fragments were blown into the package lid. Figure 4-6 shows the completely destroyed test assembly. The shockwave and shrapnel acting directly on the CASTOR package moved it approximately 7 m away from its original position along with overturning the package as shown in Figure 4-7.



Figure 4-7: Package thrown out of pre-test

Although the closure lid was exposed to fire and severely hit by tank wagon fragments, post-test investigations demonstrated that no loss of leak tightness occurred.

4.4.2 Drop Test (200 m) with Half Scale TN 8/9 Package



Figure 4-8: 1:2 scale model TN 8/9 package and helicopter before test

Another test within the BAM research project consisted of a 1:2 scale model of a Type B package which had been tested and certified to the IAEA transport regulations being lifted and dropped from a helicopter at a height of 200 meters (Figure 4-8). The package (a TN 8/9 model) consisted of a cylindrical cavity made of 12.5 mm thick steel sheets, and 100mm lead gamma shielding between outer and inner steel sheets. At both ends of the package, there were circumferential impact limiters filled with balsa wood. The total weight of the package was 4 125 kg, including a steel tube of 75 kg representing the package contents.



Figure 4-9: Package after drop from 200 m, penetrating concrete layer

A 20x30 m concrete drop target was selected. The target structure consisted of 60 cm layer of pit gravel; 40 cm concrete reinforced by steel mats. The model struck the target in an inclined, nearly horizontal position, penetrated the upper concrete layer, and caused a crater approximately 75 cm deep, 3 m long, and 1 m wide (Figure 4-9). The package was in freefall for 6.35 seconds, corresponding to an impact velocity of 225 km/hr. Figure 4-10 shows the TN 8/9 model after being lifted out of the penetrated concrete target. As a result of this impact, the following observations were made:



Figure 4-10: Package after lifting off the concrete ground

- (i) both shock absorbers sheared off as well as all clamping bolts. The lid shock absorber was nearly completely flattened.
- (ii) pressing of the cavity's closure and compressing of the respective screws, the lock could only be removed by machine.
- (iii) complete flattening of the cooling fins in the impact area, destruction, and loss of the concrete-resin mixture.
- (iv) no loss of integrity of containment components.
- (v) no leaks could be detected through bubble testing, i.e., no leakage $> 10^{-3}$ mbarL/s occurred. [35]

As a result of this test, BAM concluded that *"for this type B package large margins of safety beyond the 9 m regulatory drop test existed"*. The package maintained its integrity, and it was resistant to leaks while being subject to an extreme impact. Since this package had been certified to the IAEA regulations, it showed that packages which meet these regulatory requirements can withstand extreme real-world impacts.

4.4.3 Drop Test (19.5 m) of Package onto Heavy Truck Road Target

Around 1982, the question concerning the drop of used fuel packages from a reactor building crane (where lifting heights can reach up to 25 m) became of interest. In response, BAM performed a drop test from a height of 19.5 m (the maximum height between test object and target that could be obtained at the BAM drop test site) onto a 1 000 tonne target layer simulating a typical heavy truck road. The package used for testing was a CASTOR 1C used fuel transport and storage package which weighed 83 tonnes, had a length of 5.455 m, and a 1.73x1.73 m cross-section. It was dropped without the use of impact limiters. During the test, the package penetrated approximately 0.55 m into the target. Measured deceleration values (60 and 70 g) indicated that the impact force from this 19.5 m drop was less than half of the peak impact force measured in a regulatory 9-metre drop of a similar package design.

4.4.4 Behaviour of Elastomeric Seals at Low Temperature (-40°C)

Regulations require packages to perform at low temperatures down to -40°C. Elastomers are the common sealing material in packages. The major concern is the elastomer's glass transition temperature, below which, the material elasticity is reduced and its ability to provide sealing force may be compromised. A study was performed to investigate the low temperature behavior of sealing systems, particularly the critical temperature at which seal materials no longer provide sealing. [36]. The study measured the gas leakage rate of various sealing materials through thermal cycles between +20°C and -70°C. The temperature at which the gas leakage rate suddenly increased was deemed the critical temperature at which the material no longer provided sealing. For all seals studied, the critical temperature was well below the glass transition temperature of the elastomer. These tests concluded that the sealing function is still preserved at low temperatures while sufficient sealing force maintains contact between the elastomer seal and the flange surfaces.

4.4.5 Aircraft Crash Simulating Tests and Calculations

Between 1978 and 1982, six full-scale tests were performed in Germany to assess the impact of steel pipe projectiles at 300 m/s (1 080 km/hr) on different packages specimens to assess the response of the package to an aircraft crash [37]. After the terrorist attacks of September 11, 2001, the assessment of aircraft crash impacts was re-examined to include the effects of large civil aircraft crashes. BAM investigated the resulting mechanical impacts from aircraft engine crash loads (represented by calculated force-time relationships after penetration of an aircraft through building structures), building debris dropping onto standing packages, and finally the thermal effects of kerosene fires. The calculations focused on the package walls, lids and lid bolts stresses, gasket temperatures, and flange (axial and radial) displacements at gasket locations to verify the components integrity and to evaluate the influences on potential leakage rates. BAM concluded that from the information gathered through the tests, *"the displayed stresses and displacements are within limits where the safety of the cask function is preserved [35]."*

4.5 Central Research Institute of Electric Power Industry (CRIEPI) Tests

The nuclear policy of Japan involves reprocessing used fuel and recycling nuclear materials. However, the storage and transport of used fuel has become increasingly important in the country's nuclear fuel cycle, leading to concerns about safety. To ensure the safety of used fuel storage and transport, various tests using full-scale packages were conducted, in addition to regulatory tests. This section provides a summary of the tests conducted by the Central Research Institute of Electric Power Industry (CRIEPI) in Japan on Type B packages. These tests aimed to assess the integrity of the packages under conditions that differed from the standard regulatory tests, such as extreme impact and enhanced immersion. The purpose was to demonstrate the packages' ability to withstand conditions that deviate from the regulatory standards and simulate real accidents that may occur during transport or storage.

4.5.1 Quality Assurance of Ductile Cast Iron Packages

CRIEPI organized *The Quality Assurance Committee on Cast Iron Casks* (the QA Committee) to carry out research on the employment of Ductile Cast Iron (DCI) packages in Japan. This was due to there being insufficient material data on fracture toughness and because brittle failure acceptance criteria were not yet established for DCI in package applications. The specimens used for these tests were sampled from full-scale DCI package bodies (with wall thickness varied from 350 to 500 mm) in order to evaluate real material data [38], [39]. The QA Committee undertook various drop tests and computer evaluations to confirm the proposed brittle failure design criteria and the integrity of the DCI package against mechanical impact.

The QA Committee developed a neutral design specification for the DCI package to ensure that the test results could be applied generally to DCI packages of different designs. The results from these tests, while being a different material than the NWMO's transportation packages, are still applicable to all nuclear fuel and high-level waste packages as a point of comparison. DCI is a "low ductility" material that is prone to fracture in very cold temperatures. These tests demonstrated that transportation packages fabricated from a low ductility material, such as DCI, can withstand severe impacts even at temperatures as low as -40°C. On the other hand, most packages are fabricated from stainless steel, which has a much higher ductility and is less susceptible to embrittlement and fracture. By comparison, a package made of stainless steel would perform at least as well against brittle fracture failure modes as a package fabricated from DCI if subjected to a similar test at -40°C.

Before the drop tests were conducted, pre-drop tests were modelled using the DYNA-30 code on the DCI package for the 9-metre drop and 1-metre puncture test conditions in different drop directions (horizontal, vertical, and corner) to find the orientation of maximum tensile stress, which was determined as horizontal. Drop tests were planned for DCI packages with a sharp flaw, and

an artificial flaw with a 0.1-mm tip radius. Fracture toughness tests were performed on specimens with a fatigue crack and artificial flaws to ensure equivalency in their fracture toughness values.

Two 9-metre drop tests and one 1-metre puncture test were performed on a full-scale DCI package. The first 9-metre drop test aimed to demonstrate the integrity of the DCI package with an artificial flaw (a crack in the package with a 20-mm depth). The second 9-metre drop test aimed to verify the proposed brittle failure design. The DCI package body was cooled down to less than -40°C (233K) before each test using vaporized liquid nitrogen, and impact limiters were attached to both ends of the package. After each 9-metre drop test, the artificial flaw was examined using an optical fiberscope, and no crack propagation was observed from the artificial flaw. The DCI package was also dropped horizontally from 1-metre onto a mild steel pin, and no penetration occurred, confirming the integrity against brittle failure with strain measurements. Sufficient fracture toughness data of full-scale DCI package bodies was obtained for quality assurance and to evaluate brittle failure.

4.5.2 Drop Test of DCI Package with No Impact Limiter

Impact limiters are common features used in many Type B package designs to absorb impact forces during accidents. They are typically removed during handling at storage facilities to access the package contents. As such, the effects of a package dropped without its impact limiter in place were studied [40]. For testing purposes, DCI packages were chosen due to their economic feasibility, and a reinforced concrete slab was used as a target for the drop tests based on the conceptual design of a storage building.

The most plausible drop orientations for a package drop accident in a storage building were expected to be vertical and oblique, coinciding with the failure of a lifting cable. Another credible accident orientation was expected to be a drop in the horizontal orientation at the time of unloading from a truck. As such, drop tests were conducted in the three drop orientations: vertical, horizontal and oblique. Test drop heights were set as 1.5 m, 7.5 m, and 17 m to correspond with different potential lifting conditions. The conclusions drawn from the tests included:

- i. The structural integrity of packages was maintained under drop test conditions even without impact limiters present.
- ii. The packages maintained leak-tightness through the testing regiment.
- iii. The assessment of integrity after the 17 m drop test suggested that packages have a sufficient margin of safety when considering package lifting operations.
- iv. No damage was observed for the package contents during testing.

4.5.3 Enhanced Water Immersion Test Beyond Regulatory Requirements

A water immersion test under a head of water at 3 000 m for one hour was performed in addition to the 15 m and 200 m immersion tests required by the IAEA regulations to test the package in

extreme conditions [40]. The specimens chosen for testing were packages designed for handling high-level waste (HLW) similar to the TN 28 VT package designs. The package body consisted of forged carbon steel and neutron shielding material. The contents of the package (basket and HLW canister) and the package's impact limiters were removed during the 3000 m water immersion test.

The internal pressure of the package cavity was continuously monitored during the immersion test. Any intrusion of water into the package cavity would have been detected as part of the test.

The maximum strain at the package body resulting from the 3 000 m immersion was found to be within the package's elastic range, meaning that no rupture was observed. The package's lid plate was found to have bowed slightly as a result of the pressure. However, it was found that the package retained its leak tightness following the 3 000 m immersion test. The results of the testing include:

- i. No leakage was detected at any sealing boundary during the immersion test and no reduction in the sealing characteristics was observed.
- ii. At 3 000 m water pressure, most of the package body was within the elastic limit and the allowable stress intensity of the material was not exceeded.
- iii. Deformation by water pressure at depth was found to be 1 mm or less for the package body and 2 mm or less for the lid.
- iv. No reduction in performance was observed for the radiation shielding.
- v. The package was found to retain its integrity during the regulatory (200 m) enhanced immersion test. A significant safety margin was found to exist with regards to exposure to a water pressure of 3 000 m depth.

4.6 Summary

The stringent IAEA transportation regulations and package safety standards were tested and validated through various demonstration tests carried out by multiple agencies internationally. These tests demonstrated the robustness of packages that abide by the IAEA regulations and standards, ensuring that workers, the public, and the environment will remain safe from the effects of ionizing radiation being transported by such packages. In addition, a number of these tests have showcased that the forces generated during regulatory tests are often bounding of credible accident scenarios as discussed in Section 3.

5. REAL-WORLD ACCIDENT RECONSTRUCTIONS

5.1 Introduction

An important tool in addressing the safety of used fuel shipments is the use of accident reconstructions. Accident reconstructions are used to predict the performance of used fuel packages and transport systems under severe, real-world accident conditions. The evaluations have been used historically to:

1. Assess the performance of specific used fuel package designs in real life accident scenarios.
2. Compare impact and thermal forces generated in historical accidents with the impact and thermal forces generated during regulatory drop and fire tests used to certify used nuclear fuel (UNF) package designs.
3. Evaluate a package's performance against the acceptance criteria in the regulations for containment (release of radioactive contents) and shielding (external dose rates).

The key elements in any accident reconstruction are the identification and quantification of the impact and thermal forces present. The impact and thermal forces for most accident reconstructions are determined based on parameters reported by first responders, investigators, and any physical measurements taken at the accident scene. However, the limitations of relying solely on official accident reports and media accounts are that important parameters (such as temperatures, fire durations, and pressures) are often not reported, or reported inaccurately.

This has resulted in two general approaches to estimating the impact and thermal forces in a particular accident scenario:

- The first approach is the use of physical modelling where actual package models are constructed and subjected to a simulated accident. This approach has been illustrated in Section 4 (e.g., Operation Smash Hit and the BAM propane explosion). This approach allows the accident to be observed and photographed in real time. The use of physical models also allows the direct measurement of accident parameters that can be used to directly calculate factors such as temperature, pressure, velocity, and decelerations.
- The second approach involves the use of analytical techniques (e.g., simulations, calculations) in the reconstruction of an accident using investigative and media reports. In this case, the impact and thermal forces are initially determined based on parameters reported by first responders and investigators. These are subsequently verified by physical measurements taken at the accident scene or on vehicles and transportation infrastructure involved in the accident. The accident is then simulated using computer models.

The U.S. Nuclear Regulatory Commission (USNRC) used this second approach to analyze a series of accidents involving severe long duration fires. In analyzing these accidents, the USNRC used

videos captured by security cameras, post-accident metallurgical examinations of rail tank cars, tanker trucks, concrete rebar, and bridge components. They also made use of physical data and computer models developed from the U.S. National Institute of Standards and Technology's (NIST) extensive testing of tunnel fires, which was conducted in an out-of-commission highway tunnel.

5.2 Examples of Analyses based on Real-World Accident Reconstructions

In 2006, the U.S. National Academy of Sciences (NAS) published a safety study of a large-scale shipping campaign for used fuel [41]. While the study concluded that existing regulatory standards provided a high degree of safety, it recommended that additional studies be undertaken to look at very long duration fire scenarios that bound expected real-world accident scenarios for a representative set of package designs that are likely to be used in future large-quantity shipping programs.

In response, the USNRC conducted a series of accident studies that looked at real-world rail and highway accidents involving long-duration fires [42]. The major goals of the studies were to identify a list of historical accidents that resulted in severe long-duration fires, and then to analyze the response of typical used fuel package designs to the impact forces and fires found in those accidents.

The studies reconstructed four accident scenarios and looked at the performance of used fuel packages for both rail and truck transport. In each of the four accident scenarios, the package designs were found to meet or exceed the regulatory requirements for containment and dose limits for severe accidents. All the scenarios examined demonstrate that Type B transportation packages certified under International Atomic Energy Agency (IAEA) standards are able to protect first responders, the public and the environment from radiological harm even under extreme real world fire scenarios.

The studies are summarized in the following subsections. Note that these studies were conducted using package designs approved in the U.S. to transport used fuel from Pressurized and Boiling Water Reactors. While all certified Type B package designs have to comply with international regulatory requirements (IAEA's SSR-6), the packages studied by the U.S. feature different specific designs than those used in Canada to transport CANDU fuel. Differences include the types of used fuel being transported, the configuration of the package (i.e., round versus square cross section), and the use of different materials for gamma and neutron shielding.

A brief description of the packages used in the USNRC studies can be found in Appendix F. Information on the UFTP, DSC-TP and BTP is provided in Section 3.4.

5.2.1 Baltimore Tunnel Fire

5.2.1.1 *Description of the Accident*

On July 18, 2001, a freight train caught fire while passing through the Howard Street railroad tunnel in downtown Baltimore, Maryland. The freight train consisted of 60 cars pulled by 3 locomotives. It was carrying paper products and pulp board in boxcars, as well as hydrochloric acid, liquid tripropylene, and other hazardous liquids in tank cars.

Eleven of the 60 rail cars derailed as the train was passing through the tunnel. A tank car containing approximately 108 263 liters (28 600 gallons) of liquid tripropylene was punctured by the car's brake mechanism during the derailment.

The exact duration of the fire is not known with certainty. Based on interviews of emergency responders conducted by the U.S. National Transportation Safety Board (NTSB), it was determined that the most severe portion of the fire in the Howard Street tunnel lasted approximately 3 hours. Less severe fires burned in the tunnel for periods of time greater than 3 hours. Approximately 12 hours after the fire started, firefighters were able to visually confirm that the tripropylene tank car was no longer burning.

5.2.1.2 *Purpose*

The accident was reconstructed by the USNRC to determine the thermal conditions that existed in the Howard Street tunnel fire and to analyze the potential effects of those conditions on three different Type B package designs certified to transport used nuclear fuel.



Figure 5-1: Image of the Baltimore Tunnel Fire

5.2.1.3 *Methodology and Assumptions*

A team of experts from NIST, the Centre for Nuclear Waste Regulatory Analyses, and the Pacific Northwest National Laboratory was assembled to analyze the Baltimore Tunnel Fire. They performed a detailed fire analysis to determine the temperatures reached by the tunnel air, wall, floor, and ceiling during the accident. They also conducted a metallurgical examination of numerous samples taken from the tripropylene tank car to verify that the damage observed for the rail car was consistent with the temperatures predicted in the fire analysis.

The temperatures obtained were then used to model the performance of the used fuel packages. A description of the packages can be found in Appendix F.

The three package designs chosen represent the different ways that used fuel could be shipped. Used fuel can be shipped in rail packages either as bare fuel that is usually loaded directly from an irradiated fuel pool, or as canistered fuel, in canisters that have been used for dry fuel storage. The TN-68 (Appendix F) is a large capacity rail package that is used to ship bare (i.e., uncanistered)

used fuel. The HI-STAR 100 (Appendix F) is a large capacity rail package that is used primarily to ship canistered used fuel (that has been stored in canisters). The NAC-LWT (Appendix F) is a legal weight truck package used primarily to ship bare used fuel assemblies.⁴ Truck packages are too small to handle canistered fuel. The NAC-LWT can also be shipped by rail.

5.2.1.4 Results and Conclusions

The study concluded that larger transportation packages resembling the TN-68 and HI-STAR 100 would withstand a fire with thermal conditions similar to those that existed in the Baltimore tunnel fire event with only minor damage to peripheral components. This is due to their sizable thermal inertia⁵ and compliance with regulatory requirements.

While a release is not expected to occur for these conditions, any release that could occur would be very small due to a number of factors. These include;

1. The tight clearances maintained between the lid and package body by the closure bolts,
2. The low-pressure differential between the package interior and exterior,
3. The tendency of such small clearances to plug, and,

4. The tendency of CRUD particles⁶ to settle or plate out.

The analysis indicates that the regulatory dose rate limits for accident conditions would not be exceeded by releases or direct radiation from any of these packages in this fire scenario. While highly unlikely, the NAC-LWT could experience some slight loss of lead shielding as a consequence of this fire scenario. However, this loss would not result in dose rates that exceeded regulatory limits. There would be no release from the HI-STAR 100 because the inner welded canister remains leak tight under the observed conditions. The potential releases calculated for the TN-68 rail package and the NAC-LWT truck package indicated that any release of CRUD from either package would be very small – less than an A₂ quantity.

In summary, the potential releases of radioactive material from all three packages are well below the internationally accepted safety standard of an A₂ quantity per week, and would not pose a risk to first responders or public health and safety.⁷

Additional information is provided in [43], [44], [45] and [46].

⁴ A legal weight truck package is a package that meets the legal weight restrictions for U.S. highway shipments.

⁵ An object with a large thermal inertia will absorb a large amount of heat with a small change in temperature.

⁶ CRUD is a colloquial term used to denote corrosion products (e.g., rust particles) that adhere to the outside of used fuel rods that become radioactive when exposed to radiation.

⁷ The A₂ quantity per week is based on limiting potential exposures to first responders and the public following a severe transportation accident to no more than the occupational dose of 100 mrem. This limit represents approximately 25 percent of the normal background dose of 400 mrem/yr.

5.2.2 Caldecott Tunnel Fire

5.2.2.1 Description of the Accident

On April 7, 1982, a tanker truck and trailer carrying 33 310 liters (8 800 gallons) of gasoline was involved in an accident in the Caldecott Tunnel on State Route 24 near Oakland, California. The tank trailer overturned and subsequently caught fire.

The overall duration of the fire is estimated at approximately 2.7 hours. However, based on NTSB evaluations of the fire debris and interviews with emergency responders, the intensely hot gasoline-fueled portion of the fire is estimated to have lasted about 40 minutes. At about 46 minutes after the start of the fire, firefighters in protective gear entered the tunnel to search for survivors and were able to approach the location of the tanker truck.

5.2.2.2 Purpose

The accident was reconstructed by the USNRC to determine the thermal conditions that existed in the Caldecott tunnel fire and to analyze the potential effects of those conditions on Type B truck packages certified to transport used nuclear fuel.

5.2.2.3 Methodology and Assumptions

The USNRC first analyzed the Caldecott tunnel fire in a 1987 study (*Shipping Container Response to Severe Highway and Railway Accident Conditions*, NUREG/CR-4829 [47]) and concluded that no radioactive release or increase in radiation level would be expected from a typical (generic) used nuclear fuel truck package in this fire scenario.



Figure 5-2: Image of the Caldecott Tunnel Fire

In this reconstruction, the USNRC evaluated the potential impact of the Caldecott Tunnel fire on a specific used nuclear fuel transportation package design – the NAC-LWT truck package.

A team of experts from NIST, the Centre for Nuclear Waste Regulatory Analyses, and the Pacific Northwest National Laboratory was assembled to develop a model of the Caldecott Tunnel fire and perform an analysis to determine the range of temperatures present in the tunnel during the fire event. The temperatures obtained were then used to model the performance of the used fuel packages.

5.2.2.4 Results and Conclusions

The results of this evaluation strongly indicate that neither used nuclear fuel particles nor fission products would be released from a used fuel shipping package involved in a severe tunnel fire such as the Caldecott Tunnel fire. The NAC-LWT design analyzed for the Caldecott Tunnel fire scenario does not reach internal temperatures that could result in rupture of

the fuel cladding.⁸ Therefore, radioactive material (i.e., UNF particles or fission products) would be retained within the fuel rods. The potential release calculated for the NAC-LWT package in this scenario indicates that any release of CRUD from the package would be very small - less than an A_2 quantity.

The potential release from the NAC-LWT package based on five-year cooled fuel is estimated to be approximately 0.01 Curies (Ci) of Cobalt-60 (Co-60).^{9,10} Since the A_2 value for Co-60 is 11 Ci, the potential release is about 0.001 of an A_2 quantity. Therefore, the potential release of radioactive material from the NAC-LWT package for the Caldecott fire scenario is well within regulatory limits and would not pose a risk to first responders or public health and safety.

Additional information is provided in [48], [47], and [49].

⁸ Fuel cladding consists of a thin-walled metal tube that forms the outer jacket of a nuclear fuel rod. If the fuel rod is heated beyond its rupture temperature, the cladding may experience a longitudinal split, allowing used fuel particulates to escape from the rods.

⁹ The A_2 quantities for radioactive materials are defined in units of radioactivity such as the Curie.

¹⁰ Cobalt-60 is the main radioactive component of CRUD (corrosion products) on the outside of fuel rods. (see also footnote 6 on page 17)

5.2.3 MacArthur Maze Fire

5.2.3.1 *Description of the Accident*

On April 29, 2007, a tanker truck and trailer carrying 32 554 liters (8 600 gallons) of gasoline overturned and caught fire on the Interstate 880 (I-880) connector of the MacArthur Maze interchange located in Oakland, California. The intense heat from the fire weakened the steel girders of the Interstate 580 (I-580) roadway above the fire, collapsing two adjacent spans (approximately 48 m (156 feet)) of the elevated roadway onto the section of freeway below.

A surveillance camera from the monitoring system of the East Bay Municipal Utility District Wastewater Treatment Plant adjacent to the roadway captured a video of the fire. This video shows the first I-580 roadway span beginning to sag around 10 minutes into the fire and collapsing completely after approximately 17 minutes. The video also shows a second span of the I-580 roadway descending slowly to the lower (I-880) roadway, beginning at about 17 minutes and reaching its final (partially collapsed) configuration after about 37 minutes (post-accident).

The collapse of the second span greatly reduced the size of the fire, but it continued to burn until about a duration of 102 minutes. As a fire management decision, the first responders on the scene allowed the fire to burn until the hydrocarbon fuel was fully consumed. At that point, the fire began to noticeably decrease in brightness, diminishing to a small glowing spot by approximately 108 minutes after the start of the fire.



Figure 5-3: Surveillance footage of the MacArthur Maze Fire

5.2.3.2 *Purpose*

The accident was reconstructed by the USNRC to determine the thermal and impact conditions that existed in the MacArthur Maze fire and to analyze the potential effects of those conditions on the GA-9 truck package certified to transport used nuclear fuel.

The MacArthur Maze accident was selected because of the severity and duration of the fire, along with the unusual structural consequences in which the heat from the fire caused the overhead roadway segments to collapse.

5.2.3.3 *Methodology and Assumptions*

A bounding fire scenario was defined for this accident based on fire modelling with the NIST's Fire Dynamics Simulator code, and the physical examination of material samples obtained onsite from the tank truck and steel girders from the collapsed overpass. Based on the modelling and sampling, the bounding scenario was represented as a fully engulfing pool fire at 1 100°C (2 012°F) prior

to the overhead roadway collapse, and as a smaller and less severe fully engulfing pool fire at 900°C (1 652°F) afterward.

Thermal modelling of the GA-4 package was conducted to determine the response of the package to the fire scenario, including the long post-fire cooldown period. Additional detailed structural and thermal-structural models were developed for the roadway and package, which showed that the falling overhead segments could impose only relatively insignificant loads on the package's stainless-steel body and depleted uranium (DU) gamma shield,¹¹ compared to the structural loading the package is designed to withstand during accident conditions of transport.

5.2.3.4 Results and Conclusions

The analysis indicates that the regulatory dose rate limits specified for accident conditions would not be exceeded for this package in this fire scenario, even though the package would be expected to lose its neutron shielding. This is because the complete loss of neutron shielding is already assumed to occur as part of the package design approval process.

The gamma shielding for the GA-4 consists of a layer of DU within the stainless-steel package body. The shielding function of this material is not affected by the higher temperatures seen in the MacArthur Maze fire scenario. There is no credible scenario in this fire accident that could result in neutron and gamma dose rates for the GA-4 package

exceeding the regulatory limits for accident conditions.

Loss of the package seals due to exceeding seal material thermal limits means that there is the potential for radioactive material to escape from the package. However, it is not physically possible for very much of it to actually escape because the lid closure bolts maintain positive clamping force throughout the transient.

Type B regulations specify a maximum allowable release rate of an A₂ per week for accident conditions. The maximum possible release as estimated for this accident scenario was one-fourth of the A₂ quantity permitted by the regulations. This predicted release estimate is below the prescribed limit and indicates that the potential release from this package in the MacArthur Maze fire scenario would not pose a risk to public health and safety.

Additional information is provided in [50] and [51].

¹¹ Because of its density, depleted uranium is often used for radiation shielding in medical radiation therapy and industrial radiography equipment, and packages for transporting radioactive materials. Most depleted uranium is produced as

a by-product of the production of enriched uranium for use as fuel in nuclear reactors. DU is only about 60% as radioactive as natural uranium.

5.2.4 Newhall Pass Tunnel Fire

5.2.4.1 *Description of the Accident*

The Newhall Pass Tunnel accident consisted of a chain reaction traffic collision and fire involving 33 commercial tractor-trailer rigs and one passenger vehicle. It occurred on a section of the southbound US Interstate 5 truck route where it passes under the main north-south lanes of US Interstate 5 in California.

A fire started near the tunnel exit and spread rapidly into the tunnel, eventually filling the entire tunnel and destroying the twenty-four tractor-trailer rigs trapped inside. The cargoes of the trucks consisted mainly of foodstuffs, and none were carrying flammable dangerous goods. The severe tunnel-fire is estimated to have lasted more than 2 hours, and possibly as long as 5 hours.

5.2.4.2 *Purpose*

The purpose of the reconstruction was to determine what effects the Newhall Pass fire would have on a used fuel package transported by truck. The Newhall Pass Tunnel accident was selected because of the long duration of the fire and the wide range of potential fire exposure scenarios, due to the large number of vehicles involved in the accident and fire.

5.2.4.3 *Methodology and Assumptions*

Since this was a highway accident, the only type of UNF package that could potentially be involved would be a legal weight truck package. The General Atomics GA-4 package was selected for this investigation, mainly because it can carry a relatively large payload

for a legal weight truck package, and therefore the potential consequences of package failure could be more severe than for packages with smaller payload capacities. The GA-4 package is designed to transport up to four intact pressurized water reactor used fuel assemblies, with a maximum total package decay heat load of 2.5 kW. Note that this is the same package that was evaluated in the MacArthur Maze highway interchange fire and roadway collapse.



Figure 5-4: Image of the Newhall Pass Tunnel Fire

Based on fire modelling and physical examination of material samples obtained onsite, a bounding fire scenario was defined for this accident. Due to uncertainties in the overall fire timeline and incomplete information on the actual cargo of some of the trucks, five specific fire modelling cases were defined to bound the possible range of fire conditions. Detailed thermal models of the GA-4 package were used to determine the response of the package to the five bounding cases defining the fire scenario.

The peak fire temperatures obtained in the modelling for vehicles at the hottest fire location and longest fire location were used to define the fully engulfing fire conditions for the GA-4 package.

5.2.4.4 *Results and Conclusions*

The study evaluated the potential for increased neutron and gamma radiation dose rates from the GA-4 as a result of exposure to the Newhall Pass tunnel fire scenario.

The analysis indicates that the regulatory dose rate limits specified for accident conditions would not be exceeded by this package in this fire scenario, even though the package would be expected to lose its neutron shielding. This is because the complete loss of neutron shielding is already assumed to occur as part of the approval process. The package's DU gamma shielding is expected to remain intact and functional even if subjected to the severe conditions of the Newhall Pass Tunnel fire scenario.

The study also concluded that the GA-4 package could experience degradation of some seals in this severe accident scenario. The maximum temperatures predicted in the regions of the lid and the vent and drain ports exceed the rated service temperature of the seals, making it possible for a small release to occur.

The potential release from the Newhall Pass fire scenario was compared to and found to be bounded by that from the more severe MacArthur Maze fire scenario, where the predicted release was approximately one-fourth of the A_2 quantity permitted by the regulations. Since the regulatory limit is specified in Type B regulations as an A_2 quantity per week for accident conditions, the estimated release is below the prescribed limit for safety.

This very conservative estimate indicates that the potential release from this package, were it to be involved in a fire accident as severe as the Newhall Pass Tunnel fire scenario, would not pose a risk to public health and safety.

Additional information is provided in [52] and [53].

6. REAL-WORLD CANADIAN TRANSPORT ACCIDENTS

This section presents a summary of the history and characteristics of severe transportation accidents that have occurred in Canada from 1979 through 2022. The summary was compiled from official accident reports and public media accounts. Four severe accidents were selected for further examination to determine the possible consequences of a used nuclear fuel (UNF) package being involved in each accident. The representative accidents were selected based on their different accident characteristics. The selections include rail accidents involving explosions, impact and severe fires, and a road accident involving a severe fire in a highway overpass.

This section also provides a brief description of the two main features used to ensure the safe shipment of UNF by highway and rail: shipping package design and transport controls.

6.1 History and Characteristics of Canadian Transport Accidents

6.1.1 Survey of Severe Canadian Road and Rail Accidents

An analysis of historical highway and rail accidents (from 1979 to 2022) was performed to identify relevant severe accidents and determine the potential impact those types of accidents could have on the highway and rail transport of UNF. The primary sources used were accident investigation reports compiled by the Transportation Safety Board of Canada, the Commission of Inquiry for the Hinton Train Collision, the evaluation of the Mississauga Evacuation by the Ministry of the Solicitor General, and historical media accounts and publications. A representative list of severe accidents is given in Appendix G. The accidents were chosen based on the presence of significant physical impacts (i.e., collisions and explosions), long-duration fires, release of dangerous goods, fatalities and injuries, and major property damage. It is important to note that none of the accidents listed involved the shipment of UNF, or the transport or release of radioactive material.

6.1.2 Characteristics of Severe Rail Accidents

Most of the severe rail accidents identified in Appendix G involved the derailment of long trains (i.e., in excess of 100 cars) and the subsequent release of non-radioactive dangerous goods (primarily flammable liquids) from tank cars. The releases from the tank cars occurred from damage to top and bottom fittings, thermal tears, and punctures (see Appendix H). A thermal tear occurs when the pressure inside a tank car increases to the point that the tank car hydraulically ruptures (i.e., splits open). This occurs because the liquid inside the tank car expands when heated. If the expansion occurs rapidly enough, the tank car can explode in what is known as a boiling liquid expanding vapor explosion (BLEVE). The release of flammable liquids most often results in long duration fires and less often in explosions. The various scenarios (accident pathways) that occur in an accident involving a tank car breach are shown in Appendix H.

Accidents involving collisions between trains occur either when the trains collide head-on, or when the front of one train collides with the rear of another train. In these cases, most of the direct impact is absorbed by the locomotives or end cars. As noted in Appendix G, there were no examples of severe accidents where two trains collided in a side-by-side impact. For NWMO shipments of UNF, these types of accidents are considered to be extremely rare because many of the rail routes that would be used to transport UNF are single track. Additionally, no tracks that intersect at 90-degree angles were identified, and therefore are not considered in this summary.

6.1.3 Characteristics of Severe Road Accidents

In contrast to severe rail accidents, there were very few highway accidents that had accident investigation reports. This is because such accidents are generally limited in scope, and the causes for the accidents are well understood or readily discerned. However, based on studies done in the U.S. (see Section 5) and as it pertains to the shipment of UNF, the most severe highway accidents involve the shipment of flammable materials. This is because the greatest impact on a UNF shipment would likely result from the effects of a large fire, such as the James Snow Parkway collision (see Table 6-1 in Section 6.1.4 as well as Appendix L). The James Snow Parkway incident involved the collision of a gasoline tank truck with another large truck beneath a highway overpass. The tank truck ruptured and spilt its flammable contents (in this case gasoline). This resulted in a large fire in a “confined” space. Fires in confined spaces may experience much higher temperatures than open pool fires prescribed by Type B package regulations. In addition, the accident consisted of a scenario where a package might suffer a significant impact after the fire (e.g., a highway overpass collapsing onto the package as a result of being exposed to high temperatures). This scenario is similar to the MacArthur Maze fire described in Section 5.2.3. It is likely that this scenario bounds the severity of most highway accidents that could occur.

6.1.4 Selection and Evaluation of Representative Accidents

A set of four severe accidents were chosen from the list in Appendix G that represent the worst categories of severe transportation accidents that have occurred in Canada. These include:

- Rail accidents with explosion (Mississauga Train Derailment)
- Rail collisions with large impacts (Hinton Train Collision)
- Rail accidents with large fires (Lac Mégantic Train Derailment)
- Highway collisions in a confined space (James Snow Highway Collision)

For the rail cases identified above, the accidents were examined using data from rail accident investigation reports, historical media accounts and publications. Important parameters included the placement of railcars after the accident occurred, the nature of hazardous goods involved, the accident timeline and the description of damage and emergency response efforts. An assessment for each accident was then conducted to assess the potential response of a UNF package to the impact force and resulting thermal (fire) environment. For the purpose of these assessments, it

was assumed that the DSC-TP would have been used for rail shipments and the UFTP for shipment by highway. As described in Section 3.4, the BTP design is excluded from assessments contained in this report as it is currently under development.

The results of the quantitative assessments are summarized in Table 6-1. The quantitative assessments are presented in Appendix J – Appendix M.

Table 6-1: Summary of quantitative assessments for selected accidents

Accident	Description	Predicted Outcome
Mississauga Train Derailment and Explosion (November 15, 1979) Appendix J	A freight train carrying hazardous materials derailed and caught fire in the middle of the town. The train was carrying a variety of chemicals, including propane, styrene, and chlorine, among others. There were several explosions.	None of the forces (impact, puncture and explosion), or the fire that occurred would be sufficient to either breach the DSC-TP wall or severely damage the DSC-TP's welded closure area.
Hinton Rail Collision (February 8, 1986) Appendix K	A westbound freight train and an eastbound passenger train collided head-on on a single-track section of the Canadian National Railway (CN) mainline. The collision resulted in the deaths of 23 people, including three crew members on the freight train, and 20 passengers on the passenger train. A fire was caused by fuel leaking from locomotives.	Neither the impact or puncture force that occurred would be sufficient to either breach the DSC-TP wall or severely damage the DSC-TP's welded closure area. The collision resulted in a very localized diesel fire that would not have seriously impacted a Type B used fuel package. There were no explosions. No release of radioactive material or increase in external radiation would have occurred under the conditions experienced in the collision.
James Snow Parkway Accident (March 24, 1986) Appendix L	A gasoline tanker truck carrying 51 000 liters of gasoline collided with a flatbed truck under a highway overpass. The tanker exploded and erupted into huge fireball. The resulting fire caused concrete to burn away, exposing the inner steel reinforcing cables of the overpass.	Neither the impact or puncture force that occurred would be sufficient to either breach the UFTP wall or severely damage the UFTP's sealing areas. A small release could be possible for the UFTP if the package seal operating temperature and fuel rupture temperature are exceeded.

Accident	Description	Predicted Outcome
Lac Mégantic Derailment and Explosion (July 6, 2013) Appendix M	A freight train carrying crude oil derailed, causing fires and explosions resulting in the deaths of 47 people and the destruction of much of the town's downtown area.	None of the forces (impact, puncture and explosion), or the fire that occurred would be sufficient to either breach the DSC-TP wall or severely damage the DSC-TP's welded closure area.

6.2 Assuring the Safety of Used Fuel during Severe Accidents

A shared goal of nuclear regulators and shippers is to reduce the overall risk of shipping UNF. This is accomplished by lessening the probability of severe accidents from happening, and by designing packages and transport systems that minimize the consequences of a severe accident should it occur.

6.2.1 Package Design

The primary method used to limit the potential consequences during a severe accident (i.e., release of radioactive material and increased radiation exposure) is the design of the shipping package. In Canada, packages used to ship UNF are certified by the Canadian Nuclear Safety Commission (CNSC) as Type B packages that are designed to withstand conditions that might result during severe transport accidents. These conditions include impacts due to large drops when loading or due to collisions during transport, severe fires, and immersion in water. As a result, Type B safety standards have specific tests that a package must meet to assess a package's ability to prevent package breaches during severe impacts, resist puncture, and preclude loss of containment or radiation shielding during large fires.

The application of Type B standards to package design has resulted in most UNF packages having common design features to address impact, puncture and fire. For example, most UNF packages have:

- Thick container walls to limit radiation exposure, and prevent puncture or breach
- Impact limiting devices, such as impact limiters or fins
- Recessed lids to lessen impact
- Welded or bolted lids
- Ports (package opening used to drain, dry or sample package contents) that are recessed with bolted lid covers
- High temperature seals and tight-fitting sealing areas

In addition, the UNF is shipped in a solid encapsulated form that is largely indispersible.

6.2.2 Transport Controls

The probability of a severe accident involving a UNF package can be reduced by requiring conditions on the way a package is transported. Potential considerations and controls for safe and secure rail and road shipments are described in the following subsections.

6.2.2.1 *Transport Controls for Rail*

Dedicated Trains

A dedicated train means that no other hazardous goods are shipped in the same train as UNF. This minimizes the threat that explosions and long duration fires could pose to a UNF package. The use of a dedicated train also eliminates the need for a train to pass through rail classification yards – where train cars are added, removed or switched around to accommodate the efficient make-up of larger trains. In addition, the use of a dedicated train often involves fewer stops and can reduce or avoid track switches. Train classification yards are a location where many train accidents occur (although the vast majority of these accidents are minor in nature).

Furthermore, the use of short, dedicated trains can offer several advantages in reducing the probability of severe rail accidents. Most severe train accidents result from derailments caused by wheel, axle and track defects, abrupt braking, and operator error. Statistically, the vast majority of train derailments occur in long trains (i.e., 100 or more cars), with the derailed cars positioned in the center of the train. Many derailments could probably be prevented by enhanced train control and monitoring for wheel and axle defects that are often precursors to a derailment.

The use of short, dedicated trains (e.g., typically ten cars or less¹²) allows a train to be configured with defect monitoring and enhanced brake control:

- Traditional trains are equipped with pneumatic brakes on railcars which act in sequence. The brakes depend on air pressure being transmitted from the front to the back of the train, with each subsequent car breaking after the preceding car.
- In contrast, electronically controlled brakes can more effectively transmit the brake signal to each railcar in the train consist. The electric pathway needed for the electronically controlled brakes also allows the use of real time monitoring for derailment precursors.

The precursors include monitoring for:

- Wheel bearing condition
- Wheel flats

¹² For example, a typical ten car dedicated train might consist of three UNF cars, four interspaced buffer cars, two locomotives, and an escort car.

- Truck hunting
- Location tracking
- Speed

Examples of specifications for electronic braking and remote monitoring are described in the Association of American Railroads (AAR) standard, *Performance Specification for Trains Used to Carry High-Level Radioactive Material* (AAR S-2043) [54]. The AAR S-2043 standard was developed by the rail industry to provide performance guidelines for trains carrying UNF and/or high-level waste (HLW). The AAR S-2043 standard also includes standards for railcars shipping HLW to enhance their crashworthiness. Compliance with the AAR S-2043 standard is not required by Canadian regulations, but it represents recommended practices for the North American rail industry.¹³

Buffer Cars

Buffer cars can be used in both dedicated and non-dedicated trains. For non-dedicated trains, buffer cars can be used to separate cars carrying UNF from locomotives or tank cars carrying other dangerous goods. In a severe accident, this would allow additional spacing between a UNF package and a tank car carrying other dangerous goods, such as flammable liquids.

Buffer cars can also be used in dedicated trains to achieve load distribution, enhancing train operations and handling.

Operating Practices

Other controls could include restrictions on transit speed, track condition, routing, and train makeup.

Transport Canada currently applies transport restrictions of these types to trains carrying one or more loaded tank cars of Class 2.3 (dangerous goods that are toxic by inhalation), and on twenty or more loaded tank cars containing dangerous goods [55]. The restrictions currently do not include rail shipments of UNF. The transport controls are implemented by Transport Canada by defining trains carrying the affected dangerous goods as key trains and requiring that such dangerous goods be transported on key routes.

The railroad industry, through the AAR, has developed recommended railroad operating practices for transporting dangerous goods that extends the concept of key trains and key routes to the rail shipment of UNF and HLW. These practices are described in AAR Circular No. OT-55, *Recommended Railroad Operating Practices for Transportation of Hazardous Materials* [56].

¹³ Canada's two national freight railways are full members of the AAR: the Canadian National Railway Company and Canadian Pacific Kansas City.

Train Consist

The concepts described in the discussions on train design and transport controls are depicted in Figure 6-1. While the diagram depicts a train that incorporates most of the design features and operation controls discussed in this section, not all of them may be needed to support a particular shipment or shipping campaign. The transportation package is the prime method for assuring transportation safety and provides a high level of assurance that a UNF package could survive the historical accidents that have occurred in Canada.

6.2.2.2 *Transport Controls for Road*

The major operating controls for highway UNF shipments are the use of security escorts, approved routing, shipment scheduling, and communications and tracking.

Use of Security Escorts

In order to provide adequate protection during transport, as well as to comply with relevant regulations and guidance, escort personnel or escort vehicles are commonly utilized by consignors of UNF and HLW. Shipments of UNF or HLW would be accompanied by one or more escorts such as nuclear security guards. These escorts should maintain constant surveillance of the shipment.

Planned and Alternative Routing

Canadian regulations stipulate that consignors of certain nuclear materials, including certain types of UNF and HLW, must submit a transportation security plan containing descriptions of the planned route, along with alternate routes to be used in case of an emergency [57]. Use of pre-assessed routes ensures that the consignor has taken into account applicable regulations and ordinances regarding the transport of hazardous materials, the feasibility and logistics of the chosen routes, and any obvious hazards that could affect the transport along the routes. This reduces the likelihood that unexpected conditions or hazards will be encountered when transporting UNF or HLW, and allows for pre-planning and dissemination of route-specific knowledge to the drivers and security escorts, further decreasing the likelihood of an incident or collision taking place along the route.

Shipment Scheduling

In Canada, regulatory guides stipulate that consignors should take into account the scheduling of UNF and HLW shipments to minimize hazards along the route (such as periods of increased traffic), make use of varied transport schedules to avoid malicious acts such as theft or sabotage, and that specifics regarding scheduling are to be treated as prescribed information. This ensures that opportunities for malicious activities are minimized, and that provisions are taken to ensure the physical safety of the UNF or HLW being transported with regards to scheduling.

Communications and Tracking

It is typical for consignors of UNF and HLW to ensure that adequate and secure communications methods are utilized during transport operations. Communication arrangements are to be made between the licensee, the carrier, and the consignee, as well as with any law enforcement agency along the route. It also is expected that consignors notify responsible police agencies along the transportation route that a shipment will be carried out, and that the carrier has the capability for immediate communication to summon appropriate response or assistance. This ensures that rapid and effective actions can be taken in the event of incidents or unexpected conditions on the route.

It is also expected that the consignor establishes a plan of action in the event that communications are lost during shipping, such as back-up communication methods. Use of tracking devices, such as transponders that can be concealed on a vehicle or in the shipment, are particularly useful in situations where communications are interrupted.

6.3 Conclusion

A survey of severe accidents in Canada was conducted. The survey revealed that most of the severe accidents were caused by the derailment of trains carrying flammable dangerous goods. There were also severe accidents involving head-on train collisions, and a highway collision of a gasoline tanker that occurred under a highway overpass that resulted in a severe fire.

The transportation accidents were sorted into four main categories, and the potential impact on a UNF package assessed for each one. The categories are shown below along with the accident used in the assessment:

- Rail accidents with explosion (Mississauga Train Derailment)
- Rail collisions with large impacts (Hinton Train Collision)
- Rail accidents with large fires (Lac Mégantic Train Derailment)
- Highway collisions in a confined space (James Snow Parkway)

The assessments show that UNF packages adequately protect the environment and public health and safety in each case, in that they would limit the release of radioactive material to levels consistent with regulatory requirements, and thus provide assurance that a UNF package could survive the historical accidents that have occurred in Canada.

While the transportation package is the prime method for assuring transportation safety, additional transport controls could be applied to reduce the occurrence or severity of severe accidents. For rail transport, these include the use of dedicated trains, standards for train design, monitoring for accident precursors, and operation restrictions such as speed limits, conditions on track condition and train car placement. For road transport, these include the use of security escorts, approved routing, and shipment scheduling.

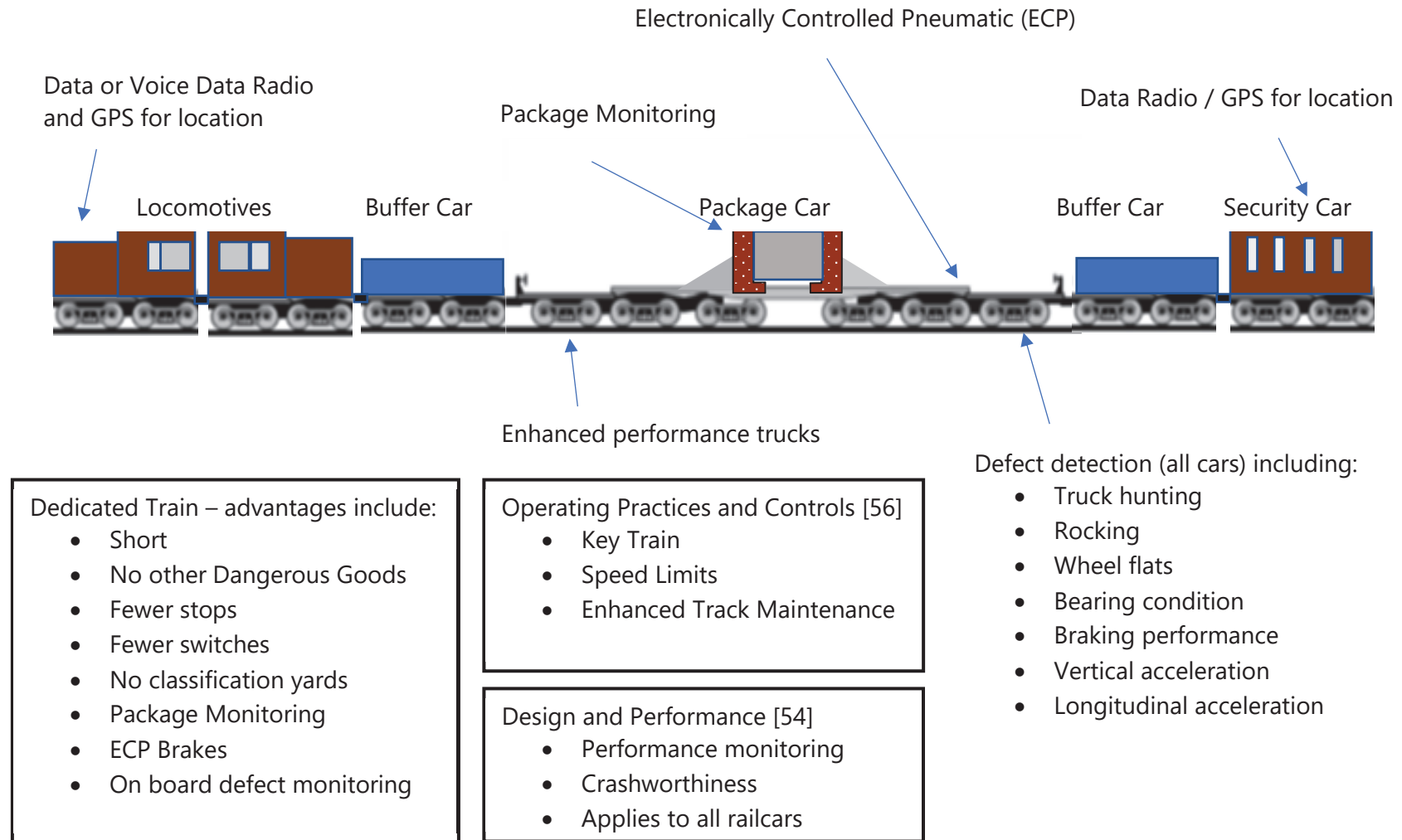


Figure 6-1: Train design and transport controls that could be applied to the shipment of UNF

7. INTERNATIONAL EXPERIENCE TRANSPORTING USED NUCLEAR FUEL AND HIGH-LEVEL WASTE

7.1 Introduction

This section utilizes publicly available information on the transport of used nuclear fuel (UNF) and high-level waste (HLW) worldwide to estimate total shipments made, the number of shipments made by key countries, and to describe transportation plans for those key countries. The Canadian Nuclear Safety Commission (CNSC) estimates there are over one million radioactive material shipments made each year in Canada [10]. Only a small number of these shipments contain UNF (estimated at 10 or less). For example, used fuel samples from nuclear power plants are shipped to Chalk River Laboratories annually for testing purposes.

The Nuclear Waste Management Organization (NWMO) is currently planning a transportation system to transport used nuclear fuel from interim storage facilities to a deep geological repository (DGR). As NWMO prepares its transportation system, it will take into account Canada's past experiences in shipping used nuclear fuel and incorporate best practices and lessons learned from 60 years of experience of other countries.

The terms *transport* and *shipment* are used in this section to refer to the movement of UNF between sites (such as from an interim storage facility to a geologic repository location). The terms do not refer to movements within the boundaries of a facility or complex of facilities. Most movements of UNF currently occur between the different stages of the used nuclear fuel cycle within a complex of facilities, such as between cooling pools to an on-site interim used fuel storage installation.

For purposes of this report, shipments by air are not considered since the NWMO is not planning to use this mode.

7.2 Historic Shipments of Used Fuel and Key Factors Influencing Used Fuel Transportation Program Composition

7.2.1 Worldwide Transportation Estimates

Radioactive materials have been transported worldwide for more than sixty years. Over that period, a stringent regulatory regime has been developed by the International Atomic Energy Agency (IAEA) and adopted internationally, including within Canada for shipments of radioactive materials. This regulatory regime has produced an impressive safety record in that there has never been a transport incident that has resulted in significant radiological harm to people or the environment.

While there have been efforts by the IAEA to establish databases to track shipments of radioactive materials worldwide, participation by the international community has been mixed, with many government authorities foregoing publishing official shipment numbers citing security concerns [58]. As such, much of the information and shipment estimates made worldwide are based on information sourced from professional organizations, conference presentations, and other government sources.

7.2.1.1 *Historic Estimate of UNF and HLW Shipments*

The World Nuclear Association estimates that about 15 million packages of radioactive material are transported around the world each year. Since 1961, when the IAEA's safe transport regulations were first issued, it is likely that over one billion nuclear material consignments have been safely completed [59].

In 2016, the U.S. Department of Energy (DOE) published *A Historical Review of the Safe Transport of Spent Nuclear Fuel* which is considered the most extensive effort to describe the worldwide record on the transport of used nuclear fuel [60]. In summary, the report estimated that at least 25 400 shipments of UNF were made worldwide, but that number could potentially be more than 44 400.

A significant finding from the report is that all these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported. In general, there have been few transportation accidents worldwide in the history of transporting UNF and none have had significant radiological consequences [60].

Revised Used Fuel Shipment Estimates

Since 2016, the purpose and volume of UNF shipments has changed dramatically to support changing national and international UNF storage and treatment policies. Several key countries have eliminated or modified their reprocessing facilities causing a growing use of on-site interim storage facilities. France and the UK have stopped accepting UNF from other countries for reprocessing while continuing to reprocess domestic UNF. This has caused other countries (notably Japan) to develop their own reprocessing capacity, thereby eliminating the maritime shipments which had previously taken place between Europe and Japan.

The U.S. terminated its reprocessing program in 1972 and decided in 1982 to develop a permanent geological disposal facility. Commercial UNF is being stored at reactor sites until a disposal facility is licensed and operational. With the exception of defense-related UNF and the international return of highly-enriched research reactor fuel, most UNF shipments in the U.S. occur between different reactor sites owned by the same utility. These shipments are undertaken to make use of available storage space, rather than build new storage facilities.

Germany shut down its last nuclear power reactor in April 2023. The UK stopped reprocessing UNF in 2022. The result is many European countries are increasing their dependence on interim storage at reactor facilities until a DGR is operational in their respective countries. Based on current developments, Finland and Sweden are expected to be the first countries to construct and operate a DGR. This shift towards using interim storage until a permanent DGR is operational has reduced the dependency on transporting UNF and HLW since 2017.

7.2.1.2 *Safe shipment of UNF and HLW*

UNF and HLW shipments are made in many countries and are conducted by power utilities, specialized private transporters, and governmental organizations. The actual transport of the UNF and HLW is often made under contract with a highly experienced transportation company with exemplary safety record. These companies often own the certified packages in which the UNF and HLW is transported.

While each shipment of UNF and HLW is different, adherence to a robust regulatory framework that places an emphasis on shipping package design safety is a common thread across every shipment taking place. This framework also requires shipments to be made in a prescribed manner to enhance safety and security.

In addition to the robustness of the packages and enhanced transportation safety regulations, UNF and vitrified HLW are solid materials which is an important factor. These materials are characterized by their stability, low solubility in water, and their ability to stay in a solid form even after an accident involving severe impact and high temperature fire (see Sections 2, 3, and 4). In Canada, used CANDU fuel is in the form of solid pellets which are contained within zirconium alloy metal tubes or “pencils”. These pencils are welded together into bundles the approximate shape and size of a fireplace log. Zirconium is used throughout the nuclear industry and has a melting point of 1 852°C (3 366°F) [61].

In the case of vitrified HLW from reprocessing, the vitrification process incorporates the radioactive products into molten glass, which is then cooled and stored in steel canisters. As a result, the fission products are immobilized, and the vitrified product is protected by the steel canister.

7.3 Countries with Strong Used Fuel Transportation Programs

UNF transportation programs support a nation’s nuclear energy program and that nation’s preferred processes for treating, storing and disposing of the used nuclear fuel. Some countries have chosen to recycle their UNF (i.e., Japan, France and United Kingdom) – also known as a closed end system. The transportation program must be capable of safely transporting hot used nuclear fuel (i.e., used fuel having both high thermal and radioactive values), reprocessed fuel, by-products of reprocessing (HLW), and eventually the disposal of both the used nuclear fuel and reprocessing by products.

The NWMO transportation program supports a once-through nuclear energy program (or open-end system) with a deep geological repository for disposal. This means the CANDU fuel passes through a reactor once, is cooled in water-filled storage pools, placed into interim dry storage and eventually transported to a permanent DGR.

7.4 Key Country Transportation Plans

This section describes key country transportation programs and their respective plans. The list of key countries was determined based on the description in Section 7.3, and includes:

- Finland (Posiva Oy)	- Sweden (SKB)	- Switzerland (NAGRA)
- France (Andra)	- The United Kingdom (NDA)	- The United States (U.S. Department of Energy)
- Japan (NUMO)		

A summary for Canada (NWMO) is included for reference purposes. Table 7-1 summarizes the status of each key country's transportation program and plans. The details presented are based on current publicly available information about transportation modes, conveyances, contents being transported, extent/scope of transportation systems and challenges. As stated above, each country's transportation program is dependent on that nation's program for managing, storing, and disposing of their used nuclear fuel. A summary of each nation's program is included for the reader's reference.

Table 7-1: Summary of key country transportation plans and UNF management programs [62]

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
Canada Nuclear Waste Management Organization (NWMO)	A consent-based process for selecting a site was initiated in 2010. Sites for consideration have since been narrowed to two regions: Ignace and South Bruce. NWMO is currently engaging with communities and interested parties, including First Nations and Métis communities in the area; the Wabigoon Lake Ojibway Nation-Ignace area in Northwestern Ontario and the Saugeen Ojibway Nation-South Bruce area in Southern Ontario. The site selection process is expected to be completed by 2024.	No	No - UNF and HLW is currently managed by the waste producers on site.	No decision has been made on mode, transport or delivery schedule. Road and rail are being considered, with the all-road option being used as the reference case.	Two regions have been identified for technical study and dialog. Federal impact assessment and licensing processes are expected to begin in 2024. NWMO's five-year strategic plan anticipates construction beginning in 2033, with operations beginning between 2040 and 2045 [63].
Finland Posiva Oy	In 2015, the Finnish government approved construction of the Onkalo DGR near Olkiluoto in the municipality of Eurajoki in western Finland.	No	No - UNF and HLW is currently stored at the reactor sites.	Transportation for the used nuclear fuel from Loviisa to the repository in Olkiluoto is not decided. Options are road, railway and sea. Road and sea are the most likely alternatives. Posiva is considering leasing a purpose-built vessel from	Posiva Oy applied for an operating licence in December 2021. The DGR facility is expected to be operational in 2023. Disposal activities are expected to begin in 2025.

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
				Sweden to reduce the number of trips. The transportation package has not been selected [64].	
France National Agency for Radioactive Waste Management (Agence Nationale Pour la Gestion des Déchets Radioactifs [Andra])	France is one of the few countries which currently reprocesses used nuclear fuel (UNF) for potential reuse in light water reactors [65]. The Cigeo DGR is intended for HLW and long-lived intermediate-level waste (LL-ILW) resulting from reprocessing operations, rather than for UNF. The Cigeo DGR site, which is near the village of Bure, was selected in 2006 [66].	Yes - since the start of operations in the mid-1960s, the La Hague plant has processed over 23 000 tonnes of used fuel from France, Japan, Germany, Belgium, Switzerland, Italy, Spain and the Netherlands. It is France's policy to return foreign HLW back to the country of ownership.	No for UNF - UNF is currently stored at the reactor sites. Vitrified HLW is stored at the La Hague reprocessing plant.	The current policy is that most of the waste packages will be transported by rail to the Cigeo DGR.	Andra submitted its construction licence application for Cigeo in January 2023. Andra plans to begin the pilot phase in the 2025–2027 timeframe.
Japan Nuclear Waste Management Organization of Japan (NUMO)	Kamoenai Village in Hokkaido prefecture and Suttu town in Hokkaido prefecture have responded to solicitation for a literature survey, which is the first stage in the site selection process. NUMO plans to complete the site	Commercial UNF from Japan was historically reprocessed in France and the UK. The reprocessed fuel was returned to Japan for use in a mixed oxide (MOX) reactor. The vitrified HLW from reprocessing was sent	Yes - at the Recyclable-Fuel Storage Center at Mutsu in the Aomori Prefecture for UNF. Currently, HLW is stored temporarily in the Aomori prefecture in northwest Japan at	No decision has been made at this time on the configuration of a transportation system from interim storage to a DGR. Historically, HLW from France and the UK was transported by ship and by	NUMO currently plans to begin repository operations before 2040.

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
	selection process before 2030.	back to Japan for storage awaiting disposal [67]. Domestic reprocessing took place at Tokai Reprocessing Plant until 2007. 360 cubic meters of HLW is stored at the plant. Construction of the Rokkasho Reprocessing Plant is expected to be completed in 2024. Currently Japan Nuclear Fuel Limited (JNFL) operates both Low-Level Waste (LLW) and HLW storage facilities at Rokkasho near Higashidori nuclear power plant [68].	the Japan Nuclear Waste Storage Management Center.	road from Tokai port to interim storage sites. Currently, domestically produced used fuel is stored at the reactor or is transported by road to an interim storage site.	
Sweden Swedish Nuclear Fuel and Waste Management Company (Svensk	A site in the municipality of Östhammar was selected in 2009.	No - while some commercial UNF has been reprocessed in France and the UK, no vitrified waste was returned to Sweden.	Yes - a central near surface interim UNF storage facility (Clab) at Oskarshamn nuclear power plant (NPP) was commissioned in 1985.	Waste is planned to be transported to the Östhammar site by a specially designed ship, the M/S Sigrid [69].	The Swedish government approved SKB's proposed repository system in January 2022. The next step is for the Swedish Land & Environment Court to

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
Kärnbränslehanter ing AB [SKB])					establish conditions for the facilities and the Swedish Radiation Safety Authority to define permit conditions. SKB expects to start repository operations sometime in the 2030s.
Switzerland National Cooperative for the Disposal of Radioactive Waste (NAGRA)	In September 2022, NAGRA announced Laegern as the preferred location for a DGR. NAGRA plans to submit a licence application by 2024 and become operational in 2060.	Yes - commercial UNF was reprocessed in France and the UK until a moratorium on reprocessing went into effect in 2006. For UNF that was reprocessed, all the resulting vitrified HLW has been packaged and returned to Switzerland.	Yes - the central storage facility (ZZL) operated by ZWILAG in Würenlingen, near the Beznau Nuclear Power Plant.	No decision has been made at this time. Road and rail transport options are being considered.	NAGRA currently plans to begin repository operations in 2060 with emplacement circa 2075.
United Kingdom National Decommissioning Authority (NDA) Nuclear Waste Services (NWS)	The community of Halethorpe established a working group, the first step in the site selection process. The communities of Allerdale, Mid Copeland, and South Copeland formed community partnerships, the second step in the site selection process. It is expected to take 5 to 20	Reprocessing at Sellafield took place from 1964 to 2022. The government's position is that the decision to reprocess in the future should be left to the commercial judgment of the owners of the UNF.	Yes - at Sellafield, the facility which will be used to store UNF and HLW until the 2070s. UNF is stored in pools at reactor sites. UNF is transported from nuclear power stations to Sellafield reprocessing facility by rail. Each flask weighs	No decision has been made at this time. Road, rail and sea transport options are being considered.	No decision has been made at this time regarding repository operation timelines.

Country and Implementing Organization	Status of Repository Site Selection Process	Reprocessing	Central Interim Storage Facility	Transportation System in Place to Move UNF/HLW to DGR	Anticipated Start of Repository Operations
	years to complete the site selection process.		more than 50 tonnes (110 000 lb), and transports no more than 2.5 tonnes (5 500 lb) of UNF.		
United States U.S. Department of Energy (DOE)	The Yucca Mountain site was characterized and approved for development as a repository by Congress in 2002. In 2010 U.S. DOE filed a motion with the U.S. Nuclear Regulatory Commission (NRC) to withdraw its 2008 licence application. Licensing processing was suspended in 2011. At this time, the U.S. Congress has not funded the project or amended the Nuclear Waste Policy Act to change the site.	The U.S. reprocessed defense-related UNF as part of its weapons plutonium production program. Small amounts of commercial UNF were reprocessed at West Valley, New York. Two commercial reprocessing plants were constructed, but never operated. The U.S. does not currently reprocess commercial UNF.	Two Consolidated Interim Storage Facility licences have been approved by NRC. Neither site is operating at this time.	Transportation modes are dependent on repository location. There is no rail transportation system currently available to the Yucca Mountain site. The U.S. DOE had planned a new rail line within Nevada providing access from Caliente, NV to Yucca Mountain.	No decision has been made at this time regarding repository operation timelines.

7.4.1 Canada (NWMO)

The NWMO's transportation program is in the early phase of planning, data collection, and community relationship building. Major decisions related to the design, transportation modes, available infrastructure, support services, and operation of a UNF transportation system are dependent on the location, timing, and operating requirements of the DGR. As the NWMO advances towards the DGR site selection and regulatory licencing processes, the transportation system design will be refined in turn.

The NWMO has published two transportation planning documents describing the transportation planning process. The *Transportation Planning Framework* [70] sets out objectives, priorities, and considerations for transporting UNF. A second document, the *Preliminary Transportation Plan* [27] provides an overview of the technical approaches, regulatory requirements and planning assumptions on which NWMO will build its system to ensure safe and secure transportation along with protection of people and the environment.

The majority of Canada's used nuclear fuel is stored at reactor sites in specially designed interim storage facilities. The UNF will be moved from these interim storage facilities to a DGR. The transportation program is planned to begin operations in the 2040s, when the DGR is licensed for operation.

7.4.2 Finland (Posiva Oy)

Posiva Oy, Finland's operating authority, is currently in the final stages of licensing a DGR near the Olkiluoto nuclear power plant. The operating licence application for this facility (the Onkalo used nuclear fuel repository) is currently being reviewed by the Radiation and Nuclear Safety Authority (STUK), Finland's regulator.

No final decision has been made on the mode of transport for moving UNF to the Onkalo used nuclear fuel repository. The options being considered for transportation to the DGR are road, rail, and sea. Road and sea are considered likely given rail is inflexible and would require significant capital investment. Annual volumes to be transported will be determined once the repository is licensed. Posiva Oy is considering the option of leasing a purpose-built vessel from Sweden, which would make one or two trips per year as part of its transportation operations. No decision has been made on the transportation package.

7.4.3 France (Andra)

France operates 58 nuclear power reactors producing nearly 72% of France's electricity. France's nuclear fleet is responsible for producing a significant amount of used fuel and radioactive waste. The keystone of France's national used fuel policy is its used nuclear fuel recycling program.

To manage the nearly 1 150 tonnes of used fuel produced each year, France decided early on to close its national nuclear fuel cycle by reprocessing its used fuel. In doing so, the French nuclear industry recovers uranium and plutonium from the used fuel for reuse, thereby reducing the volume of HLW over the life of the program. Through recycling, up to 96% of the reusable material in used fuel can be recovered. About 4% of the HLW is vitrified, then placed in stainless steel canisters and stored at the La Hague site, pending disposal.

Orano is the French company (resulted from a restructuring of Areva) in charge of the nuclear fuel cycle and manages the waste from the country's nuclear power plants. After a few years of cooling in pools at nuclear power plants, used fuel is shipped to the Orano La Hague reprocessing plant in licensed packages by road, rail, or sea. Nuclear material transport and storage services are provided through Orano TN. Since 2017, Orano TN uses the NUTECH HORIZONTAL MODULAR STORAGE (NUHOMS) System, a dual-purpose storage and transportation canister [71].

Used fuel from other countries is also sent to La Hague plant in Normandy for reprocessing. This plant has the capacity to reprocess up to 1 700 tonnes per year of used fuel in its UP2 and UP3 facilities. Since the launch of La Hague in 1976, it has treated nearly 40 000 tonnes of radioactive material as of February 2023 [72]. The treatment extracts 99.9% of the plutonium and uranium for recycling, leaving 3% of the used fuel material as HLW which is vitrified and stored there for later disposal.

Andra, a state-owned undertaking, has the mission of sustainable management of radioactive materials and the creation of Cigeo. On January 16th, 2023, Andra submitted the construction licence application for Cigeo, the French the DGR facility for the most highly radioactive waste. This is a crucial step marking both a culmination and a new start for the project [66]. Cigeo is to be built near the Village of Bure in the Paris Basin of France. The chosen mode of transport for the Cigeo project is rail, with a connection from the site to the national rail network. Vitrified waste (HLW) transportation packages are in the process of being designed and certified.

7.4.4 Japan (NUMO)

Implementation of Japan's UNF disposal program is the responsibility of the Nuclear Waste Management Organization of Japan (NUMO). Japan has been reprocessing its used fuel for over 50 years, which historically included shipping the UNF to British Nuclear Fuels Ltd (UK) and COGEMA (France) facilities for reprocessing. The reprocessed nuclear fuel and vitrified wastes were shipped back to Japan for reuse and interim storage.

Between 1969 and 1990, more than 160 shipments of UNF were made between Japan and Europe, traveling over 8 million kilometers. Recovered fissile materials were returned to Japan as MOX fuel. The first shipment to Japan of vitrified HLW from reprocessing took place in 1995 and the

12th and last shipment from France in 2007. Over the 12 years, a total 1 310 canisters containing almost 700 tonnes of vitrified HLW were returned to Japan [67].^{14 15}

The European shipments were off-loaded at the port and transported by specialized road vehicles to JNFL's Rokkasho facility. This facility services four functions: reprocessing of UNF, vitrification and storage of HLW, uranium enrichment, and low-level waste disposal (see Table 7-2). Used fuel has been accumulating at Rokkasho since 1999 in anticipation of its full-scale reprocessing operation starting (shipments to Europe finished in 1998).¹⁶

Japan's nuclear fuel cycle plan is dependent on reprocessing its UNF at the Rokkasho Nuclear Fuel Reprocessing Facility, which is planned to have an annual capacity of 800 tons of uranium and 8 tons of plutonium. At the end of 2012, Japan had a total of 14 460 tonnes of used fuel in storage, much of it at reactors using dry storage with convection cooling. In March 2017, JNFL had 2 968 tonnes of used fuel in storage at Rokkasho, which has a total capacity of 3 000 tonnes.

Table 7-2: Facilities at Rokkasho Aomori Japan [73]

	Reprocessing	Vitrified Waste Storage Capacity	Uranium Enrichment Plant	LLW Disposal Facility
Capacity	Main plant capacity: 800 ton U/y Used Nuclear Fuel Storage Pool: 3 000 ton U	Waste returned from overseas: 1 440 canisters Future capacity from reprocessing: 3 000+ ton	Current capacity: 1 050 tons Separative Work Unit (SWU)/y Total capacity: 1 500 SWU/y	Authorized capacity: 200 000 m ³ Total capacity: 600 000 m ³
Schedule	Constructed 1993 Operational ~ 2024 ¹⁷	Constructed 1992 Operational 1995	Constructed 1988 Operational 1992	Constructed 1990 Operational 1992

Tokai had been the main site for Japan Atomic Energy Agency's HLW treatment and disposal until Japan's Nuclear Regulation Authority (NRA) approved the decommissioning of the Tokai reprocessing plant in 2018. Decommissioning will require 70 years to complete. An immediate priority is to reduce the risk from radioactive waste held at the plant. Accordingly, the intention is to complete the vitrification of all the HLW by 2028. To accommodate the vitrification process, the storage capacity at Tokai was increased from 420 HLW packages to 630. Eventually, the HLW packages will be moved to a final disposal facility which is to be constructed by NUMO.

¹⁴ The double hulled ships used to transport the UNF were built in the 1980s and continue to meet the highest safety rating of the International Maritime Organization (IMO), a United Nations regulatory agency. The ships' safety record is second to none, without a single incident resulting in the release of radioactivity.

¹⁵ There is a discrepancy between the numbers reported by the World Nuclear Association and the Federation of Eclectic Power Companies of Japan table.

¹⁶ Since 2011, following the Fukushima Daiichi tsunami accident, the Nuclear Regulation Authority (NRA) has been applying lessons learned to all of Japan's nuclear facilities. This has caused delays in the construction and licensing for operation of several key facilities, including the reprocessing facility at Rokkasho and the interim used fuel storage facility in Mutsu, Aomori prefecture.

¹⁷ In January 2023, JNFL announced that it expects the reprocessing plant under construction at Rokkasho in Japan's Aomori Prefecture to begin commercial operation in 2024.

The Japan Atomic Energy Agency (JAEA) also operates used fuel storage facilities at Tokai, containing an estimated 110 tonnes of UNF in 2014. In May 2016, a new entity was created responsible for reprocessing, the Spent Fuel Reprocessing Organisation (SFRO), which will collect funds from the utilities and contract out reprocessing and MOX fuel fabrication to JNFL.

Nuclear Fuel Transport Co, Ltd. (NFT) is the only company that transports used nuclear fuel in Japan and boasts of a flawless safety record with no accidents since its formation. NFT graphically illustrates in Figure 7-1 and Figure 7-2 the transportation of UNF and HLW in Japan. NFT owns and maintains the road transports, ships, and packages used to transport used fuel and high-level vitrified waste in support of Tokai and Rokkasho facilities.

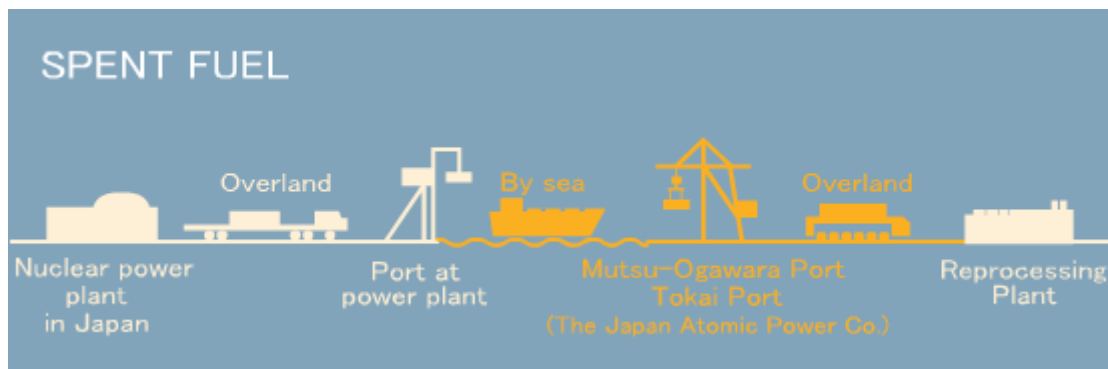


Figure 7-1: Transportation of UNF in Japan

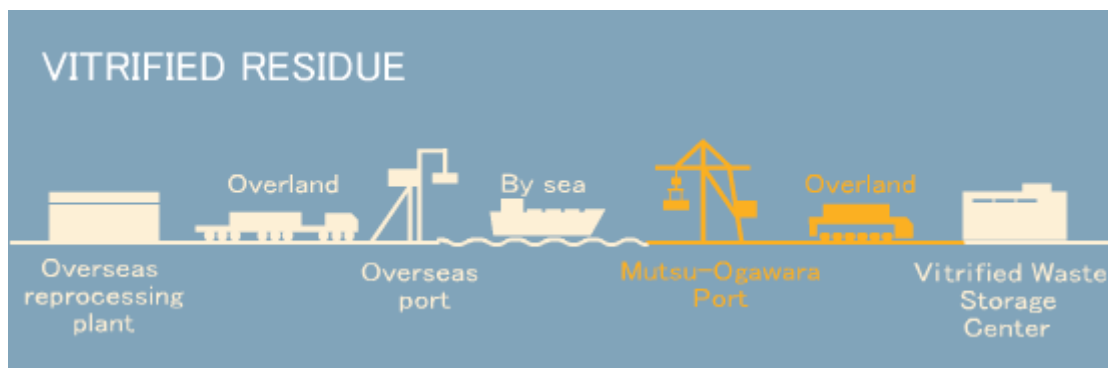


Figure 7-2: Transportation of HLW in Japan

7.4.5 Sweden (SKB)

Nuclear power companies in Sweden jointly established the Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB (SKB)) in the 1970s. SKB's assignment is to manage and dispose of all radioactive waste from Swedish nuclear power plants in such a way as to secure maximum safety for human beings and the environment. Twelve nuclear power reactors have been built in Sweden and ten of them are still in operation.

The keystones to SKB's management system are:

Operating facilities

- A marine based transport system which has been in operation since 1983.
- The transportation system includes the Sigrid, 10 transport packages for used fuel, 2 packages for used core components and 5 terminal vehicles for transport at the ports.
- A central interim storage facility for used nuclear fuel (Clab) facility operating since 1985.
- A final repository for short-lived, low and intermediate level waste, SFR, in operation since 1988.
- An encapsulation plant for used nuclear fuel, in testing phase.

Planned or in-construction facilities

- A deep disposal facility (DDF) for encapsulated used fuel and other long-lived radioactive wastes.

All the nuclear power plants and the Clab facility have their own ports, therefore SKB's transportation system is marine-based. This allows for a higher load capacity per trip and low interference with road and rail traffic.

The Sigrid, a new INF-3 special purpose ship, transports used nuclear fuel and nuclear waste from Sweden's nuclear power plants to Clab at Oskarshamn and the waste facilities at Studsvik and Forsmark. It has been designed to the most restrictive IMO rules concerning floatability after damage, similar to those for ships carrying chemicals in bulk. The ice breaking capability of the ship increases the availability in winter conditions.

In Sweden, more than 80 large UNF transport packages are moved annually from nuclear power plants to Clab, located at Simpevarp, about 25 kilometers north of Oskarshamn. Initially, the used fuel is stored at the nuclear power plant, but after about a year it is moved to Clab where it is stored in underground pools. Today there are approximately 77 750 tonnes of used nuclear fuel in interim storage in the Clab facility outside Oskarshamn. Clab has been operating since 1985 [74].

When a repository is licensed, the UNF and HLW will be moved to the repository which is to be constructed in Forsmark in the Östhammar Municipality for final disposal. Transportation of the encapsulated UNF from Clab to the repository at Forsmark is to be by marine transport using the Sigrid. This transportation system is illustrated in Figure 7-3.

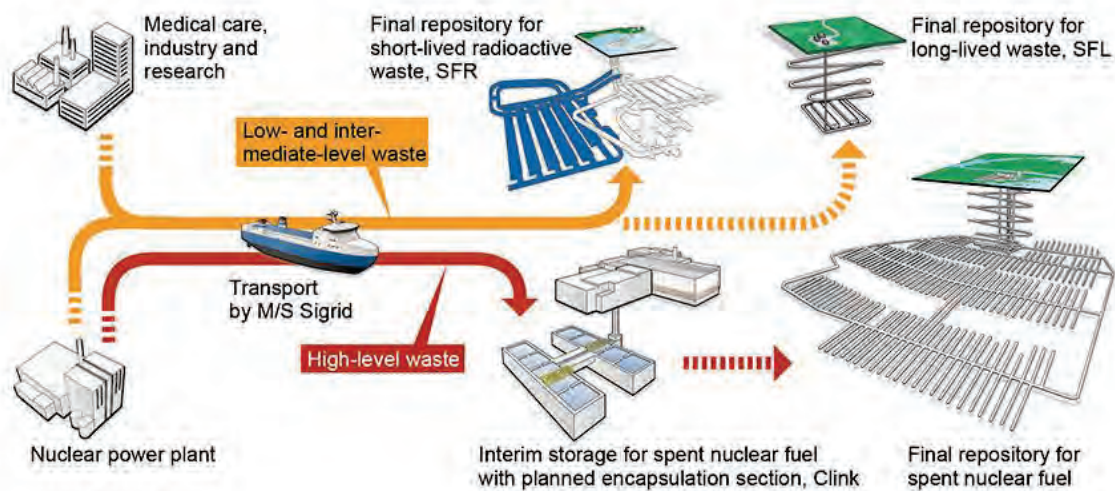


Figure 7-3: Radioactive waste management and transportation system in Sweden [74]

7.4.6 Switzerland (NAGRA)

The Swiss Federal Nuclear Energy Act stipulates that radioactive waste must be disposed of in Switzerland in a DGR. In 1972, a national co-operative for disposal of radioactive waste (NAGRA) was set up, involving power plant operators and the federal government. Currently, both wet and dry interim storage sites are used in Switzerland.

Used fuel and HLW are stored at the Zwiilag interim storage facility located in Würenlingen in Canton Aargau. The facility provides storage capacity for transport and storage packages containing used fuel assemblies and other high-level waste. The ZWIBEZ interim storage facility, where used fuel assemblies and low-level waste are also held, is located on the site of the Beznau nuclear power plant. The Gösgen nuclear power plant houses a wet storage facility for used fuel assemblies [75].

The CASTOR package is used to move used fuel and HLW to interim storage. The CASTOR package is a storage and transport package for radioactive materials and is a trademarked package. The packages are about six metres high, are cylindrical shaped, weigh about 130 tonnes and are made of steel.

Once the containers arrive at the interim storage facility in Würenlingen, they are tested for leak tightness before being moved to the storage hall of the facility, which currently holds 34 containers (equivalent to 17% of the maximum storage capacity).

In 2022, NAGRA announced its siting proposal for the construction of a DGR. NAGRA's plan is to submit an application for a general construction licence in 2024. No decision has been made

related to the transport of used fuel from the reactor sites to the repository. Road and rail options are being considered.

7.4.7 United Kingdom (National Decommissioning Authority)

The National Decommissioning Authority (NDA) is tasked with decommissioning the UK's 17 nuclear sites and the siting and operation of the nation's disposal facilities. They are the owners of one of the largest nuclear decommissioning and remediation programs in Europe and play an important role in supporting government's aspiration for the UK to be a global leader in the civil nuclear sector [76].

In 2021, NDA launched Nuclear Transport Solutions (NTS) which consolidated the UK's two nuclear transportation companies, Direct Rail Services (DRS) and International Nuclear Services (INS). NTS will inherit one of the world's most experienced nuclear shipping companies, having delivered over 180 shipments of UNF, MOX Fuel, and HLW over a 40-year history. DRS operates a fleet of more than 100 locomotives and since 1995 has transported nuclear material over 5 million miles by rail in the UK. INS operates three specialist nuclear transport ships. So far it has shipped over 2 000 nuclear packages some 5 million miles to countries including: Belgium, Finland, France, Germany, Greece, Italy, Japan, the Netherlands, Portugal, Sweden, Switzerland and the USA.

Radioactive Waste Management Limited (RWM) is an NDA subsidiary responsible for providing a range of waste management services including delivering a geological disposal facility in Britain. This includes finding a suitable site with a willing community to host this permanent and safe solution for managing radioactive waste.

NDA has several varieties of used nuclear fuel to manage until they can be placed in a geological disposal facility, circa 2075. As of April 2022, the UK had six operating nuclear power stations. The stations comprise ten Advanced Gas-cooled Reactors (AGRs) and a single Pressurised Water Reactor (PWR) - generating about 10% of the UK's electricity supply. Eleven Magnox nuclear power stations and three Advanced Gas-cooled Reactor (AGR) stations have stopped producing electricity; they are now being decommissioned.

The long-term management policy of the UK Government is geological disposal in a Geological Disposal Facility (GDF). There is no GDF yet operating but the UK Government launched a site selection process in 2020 to find a volunteer host community with suitable geology.

The NDA's policy is waste from reprocessing overseas used fuel is to be returned to the country of origin as soon as practicable after vitrification. About 1 780 canisters of vitrified HLW and smaller quantities of other wastes are to be exported. All reprocessing contracts with overseas customers signed since 1976 include a provision to return packaged wastes or their equivalent back to the country of origin. NDA plans to complete the returns by around 2025.

7.4.8 United States (Department of Energy)

Responsibility for transporting UNF and HLW in the U.S. is divided between three U.S. DOE offices and the private nuclear power utilities. The U.S. DOE Office of Environmental Management (EM) is responsible for addressing WWII and Cold War environmental legacy materials resulting from decades of nuclear weapons production, foreign research reactor UNF return, and government sponsored nuclear energy research. This includes the transportation of UNF and HLW within and between DOE laboratories, and to waste management sites. EM transports UNF and radioactive waste using dedicated trains, road, leased barges, and ships.¹⁸

The second U.S. DOE office is a partnership between the Naval Nuclear Propulsion Program and U.S. DOE National Nuclear Security Administration (NNSA) [77]. These agencies supply the nuclear power plants used by the U.S. Navy, including the disposal of the UNF and reactor cores. This program primarily transports by rail using dedicated high-security trains.

The Office of Civilian Radioactive Waste Management (OCRWM) is the third U.S. DOE office and was established by the Nuclear Waste Policy Act of 1982. OCRWM is responsible for the construction and operation of a national DGR, and for the transport of civilian and U.S. DOE UNF and HLW to that national repository. In 2010, the U.S. DOE Office of Civilian Radioactive Waste Management, was defunded by Congress and the responsibility for directing and implementing the U.S. DOE's Nuclear Waste Policy Act activities related to Yucca Mountain were assumed by the U.S. DOE Office of Nuclear Energy.

Most of the UNF that would be shipped to a DGR is commercial UNF currently stored at 81 nuclear power plants in 34 states.¹⁹ Almost all the UNF is currently stored in canisters that are housed in concrete overpacks. The current plan is to ship the canistered UNF in large Type B transportation packages that could weigh up to 100 -125 tons by rail for the cross-country movement. Some reactor sites lack rail access; therefore the U.S. DOE is planning to use barges and specialized heavy-haul trucks to transport the UNF to intermodal transfer sites where the transportation packages can be transferred onto special purpose rail cars [78].

The commercial UNF owners are considering the use of centralized interim storage facilities until the national repository becomes operational. Two privately owned storage facilities are currently

¹⁸ The U.S. DOE Waste Isolation Pilot Plant (WIPP) transportation program is operated by US DOE Office of Environmental Management. WIPP is often referenced as a model program for future UNF and HLW shipments. Even though the waste being transported is TRU waste (plutonium or alpha radiation, see Appendix A), the program uses enhanced packaging and transportation requirements similar to those used for UNF packages. As of May 27, 2023, WIPP has completed 13 473 shipments safely and securely and traveled over 25 000 000 km. The Western States Technical Advisory Committee and U.S. DOE prepared and agreed to use the Western Governors' Association (WGA) WIPP Transportation Safety Program Implementation Guide (WIPP PIG) as the basis for transporting TRU waste to WIPP. The WIPP PIG has been accepted by all the other regions and has been used for other radioactive waste shipments including Cs-137 and Foreign Research Reactor Spent Fuel return programs, since 1998.

¹⁹ Commercial UNF comprises approximately 6 300 MTHM of the anticipated maximum repository inventory of 7 000 MTHM. U.S. DOE UNF comprises approximately 2 268 MTHM, naval UNF comprises approximately 65 MTHM (for a total U.S. DOE allotment of 2 333 MTHM), and HLW comprises the balance of approximately 4 667 MTHM.

licensed by the NRC [79], [80].²⁰ The storage facilities are designed to store UNF that has been loaded into canisters and is currently stored at reactor sites. Due to the size and weight of these transportation packages, rail is the most likely mode for the cross-country movement to an interim storage facility [81]. For this case, the owners of the UNF would be responsible for the transportation to the private interim storage facilities. As with the U.S. DOE program, heavy-haul truck and barge may be required to move the UNF to an intermodal transfer facility to be loaded on to specialized rail cars [82].

²⁰ Interim Storage Partners LLC's Consolidated Interim Storage Facility in Andrews County, Texas, and Holtec International's (Holtec) Consolidated Interim Storage Facility (CISF) in Lea County, New Mexico.

8. FREQUENTLY ASKED QUESTIONS/COMMENTS

8.1 Will the package open during a transportation accident?

Type B packages, such as those utilized to transport used fuel, are required to meet strict regulatory standards that demonstrate a package's ability to withstand severe transportation accidents without a significant release of radioactive material. To meet the release criteria in the regulations, used fuel packages incorporate various design features that limit damage to the package body and lid. These design features include impact limiters to protect the lid and seal system during accident conditions, thick package walls and tightly secured lids that are either welded or bolted shut.

Bolted lids on used fuel packages are typically secured with a large number of highly torqued bolts that are closely spaced. The large number of bolts assures that the lid will remain in place even in the unlikely event that a few bolts are damaged. The highly torqued bolts compress the package seals and hold the lid tight to the package body. Bolted lids use double O-ring seals. Bolts and seals are inspected prior to each shipment. Seals are required to be changed periodically, and whenever damage is found during package loading. In addition, the package is leak tested prior each shipment. Some package designs, such as the DSC-TP, use welding as the closure system and the welds are tested to ensure the package is safely closed.

Section 3.4 describes the design of the bolts and seals on the UFTP and DSC-TP packages. Section 4 describes the tests that are used to demonstrate the effectiveness of the package safety standards and regulations.

In 2016, the U.S. Department of Energy (DOE) published *A Historical Review of the Safe Transport of Spent Nuclear Fuel* which is considered the most extensive effort to describe the worldwide record on the transport of used nuclear fuel [60]. In summary, the report estimated that at least 25 400 shipments of UNF were made worldwide, and that number could potentially be more than 44 400.

8.2 Will the package puncture during a transportation accident?

The three transport packages which NWMO is considering in their transportation program are the UFTP, DSC-TP and BTP. While the latter is still in development; the UFTP and DSC-TP have been designed and certified with a wall thickness of approximately 27 cm (stainless steel) for the UFTP and over 50 cm for the DSC-TP (carbon steel shell encased in high density concrete). Due to these thick walls and lids, these used fuel packages are unlikely to be punctured during severe accidents. As shown in Section 3.2.1.3, punctures have not been observed in severe historical puncture-type rail accidents for rail tank cars with wall thicknesses of at least one (1) inch. It is therefore highly unlikely that a used fuel package design being considered by the NWMO would be punctured during a severe transportation accident.

8.3 How many deaths have occurred as a consequence of accidents during the transportation of used nuclear fuel?

Used fuel has been shipped worldwide for over 60 years. During that time, there have been no deaths or serious injuries resulting from the release of radioactive material from used fuel packages during a transportation accident. Recent data from the U.S. Department of Transportation [83] shows that there were only 47 reported incidents for the approximately 30 million shipments of all types of radioactive material made between 2013 and 2022. None of these accidents resulted in a fatality or serious injury. Most of the 47 incidents involved small packages shipped by air or highway. In contrast, there were 63 reported fatalities during the same period involving other dangerous goods, mostly involving the shipment of gasoline by tanker truck.

The excellent safety record is due in large part to robust requirements for shipping radioactive material. Most of the incidents and fatalities that occurred in the shipment of dangerous goods resulted from breached containers carrying flammable, explosive, or toxic liquids or gases. In contrast, used fuel is an encapsulated solid, which is not readily dispersed, is not explosive or flammable and is shipped in packages designed and tested to withstand severe accidents.

The U.S. DOE's *A Historical Review of the Safe Transport of Spent Nuclear Fuel* [60] estimates that between 25 400 and 44 400 shipments of UNF have been made worldwide, and that all of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported.

8.4 Will people along the transportation routes for used nuclear fuel be unknowingly exposed to high levels of radiation?

The regulatory requirement for radiation exposure from all radioactive material transport packages, including used fuel packages, is based on limiting the exposure of an individual to dose levels that would not impact their health or safety.

8.5 Are package certification tests adequate when conducted with scale models or simulations?

To demonstrate that a package design meets the regulatory requirements, the International Atomic Energy Agency (IAEA) regulations allow physical testing, and analytical calculations, or a combination thereof. Physical testing can include full-scale tests, scale model tests, or mock-ups of specific parts of a package. The intent is to allow an applicant to use accepted engineering practices to evaluate a package design. Regardless of the method used, documentation should be sufficiently accurate and complete to allow an approving authority (i.e., the Canadian Nuclear Safety Commission in Canada) to determine that all safety requirements have been met and all

modes of failure considered. In practice, a package design for used fuel typically uses a combination of computer modelling, scale model testing and full-scale mock-ups of package components.

Scale model testing provides a number of benefits, such as allowing for evaluation from many drop angles to determine the orientation that results in the package suffering the maximum damage. The impact forces on the scale models can then be benchmarked or verified against computer simulations, as well as scaled up to predict the forces on a full-sized package. Scale model testing is a well understood and often practiced testing method. The regulations provide guidance on how to accurately perform scale testing. There is a robust body of knowledge and experience in industry with respect to scale model testing.

Other analytical tools (i.e., computer modelling) are also well suited to other aspects of package certification, such as assessing a package's response to the fire test. Thermal response can be accurately predicted by computer modelling because the thermal properties of materials used to fabricate used fuel packages are well documented and the dynamics of fires is well known. Computer modeling and analysis software are subjected to rigorous validation and verification testing before being used to simulate transportation package testing. For example, ANSYS, a popular analysis tool, meets the requirements of ASME NQA-1, a quality standard endorsed by the United States Nuclear Regulatory Commission. Computer modeling methodology and results must also be documented in detail as part of a transportation package's safety analysis report for review and approval by the relevant nuclear regulator.

The use of full-scale testing, while useful for validating computer models and analytical calculations, features its own disadvantages. There are very few test venues that can accommodate the full-scale testing of a large used fuel package. The costs of using full-scale packages to determine the most damaging orientation of tests are prohibitive and may require highly specialized facilities and testing equipment. In addition, full-scale testing may not always lead to the most robust design. The acceptance criteria for full-scale testing are pass-fail. On the other hand, when designs are based on computer modelling, safety margins or more stringent acceptance criteria are often applied. Design by computer modelling is an accepted engineering practice used in various other industries such as the aerospace and automobile industries.

The use of a particular method or combination of methods is left to the discretion of the approving authority who must make the ultimate decision that a used package design meets the safety regulations.

Additional information is provided in Section 3.3 and Appendix A.

8.6 Given Canada's limited experience in transporting used nuclear fuel when compared to other countries, how can you be sure it will be done safely?

The ability to ship used fuel safely in a country is not always closely correlated to the number of shipments that have historically been made in the country.

Used fuel has been transported worldwide for more than 60 years. Over that period of time, a stringent regulatory regime has been developed by the IAEA and applied internationally as well as to Canadian shipments of UNF. This has resulted in a specialized world-wide industry that has focused on the design and fabrication of transport packaging, as well as transportation logistics and safety. It has become a routine practice for countries and shippers to share processes and experiences. In addition, many facilities making UNF shipments rely on the use of international specialized service providers who routinely ship UNF. Canadian entities (including NWMO) work closely with each other as well as with these international service providers to ensure that expertise and best practices are applied to Canadian UNF and HLW shipments. Examples include NAC International (U.S.), HOLTEC (U.S.), Nuclear Transport Solutions (U.K.), Orano (France), Edlow International (U.S.), Hittman Transport Services (U.S.), GNS (Germany), and Nuclear Fuel Transport Co., Ltd. (Japan).

8.7 Do tests ensure that the package can perform in extreme cold conditions (e.g., -50°C)?

Used fuel packages are tested to ensure they can perform safely in extremely cold conditions. The IAEA requires package designs to be evaluated for temperatures ranging from -40°C to +38°C, which represent the typical range of temperatures experienced during transport in most geographical regions. Approving authorities have the ability to require package designs to be evaluated for temperatures lower than -40°C and/or to require additional conditions during transport, such as limits on time of shipment.

8.8 What happens if the package rolls off a cliff, falls off a bridge, or rolls down a rock face?

The particular damage that a used fuel package experiences during an impact is determined largely by the drop height (kinetic energy), orientation, and relative "stiffness" of the package versus the impacted surface. The stiffness refers to an object's ability to absorb force without deforming (i.e., fracturing or bending).

Compliance with the IAEA drop test (a 9 m drop test onto an unyielding surface) results in a used fuel package that is stiffer than almost any object that it would impact (including cement, rock, transport vehicles, etc.). This implies that most of the damage, should a package roll off a cliff, fall

off a bridge, or roll down a rock face, would occur to the objects being impacted rather than the package itself.

It is also unlikely that a package would encounter an object that is stiffer than the unyielding surface - a surface engineered with infinite stiffness – used in the package drop testing. The unyielding target redirects all kinetic energy back into the package rather than the ground, resulting in a test that is more severe than even extreme accidents (such as a direct collision with a train). Section 3.2.1.2 provides further explanation of how the regulatory drop test bounds the impacts in severe accidents.

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APPENDIX A ADDITIONAL INFORMATION ON RADIATION TYPES

Four of the most common types of ionizing radiation emitted by radioactive materials are described in this appendix and shown in Figure A-1. Dose types as mentioned in the paragraphs below are illustrated in Figure A-2. More detailed information is available in [84].

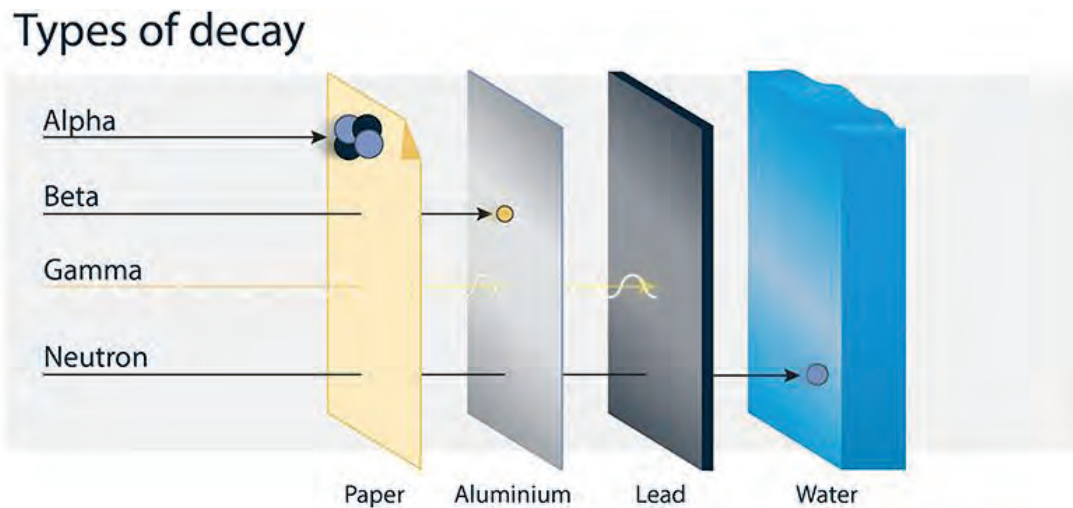


Figure A-1: The penetrating power of ionizing radiation based on radiation type [7]

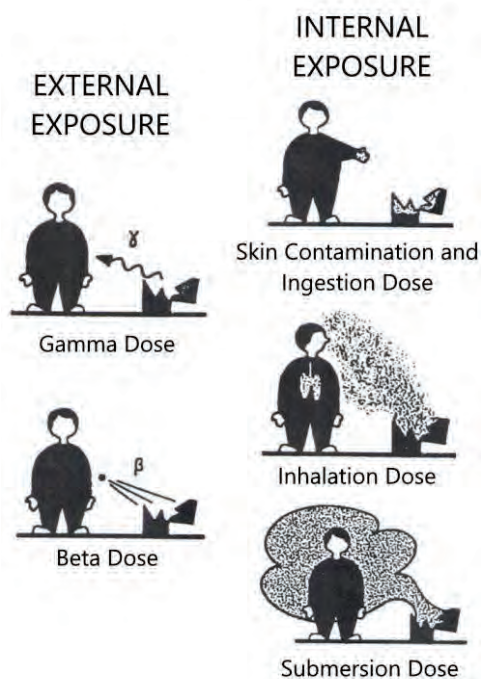


Figure A-2: Dose types for external and internal exposure

Alpha Radiation

Alpha radiation consists of two protons and two neutrons and is identical to the nuclei of a helium atom. Alpha particles are relatively heavy particles and carry with them an electric charge. As such, they will give up their energy within a very short distance (only a few centimetres in air) from the source mostly by causing ionization. The implications of this are that alpha radiation does not penetrate most materials very well - and thus can be easily shielded. In fact, most alpha particles cannot penetrate the dead layer of cells on the skin surface and therefore do not present any hazard while the alpha-emitting radionuclide remains external to the body.

However, if the material becomes ingested or inhaled into the body then the alpha particles can ionize atoms in living cells. The rate of ionization in this case is very high and significant cell damage can occur. Another implication of the lack of penetrating power is that it makes alpha radiation difficult to detect. Special instruments are required.

Beta Radiation

Beta particles are electrons emitted from a radionuclide. As such, they are much smaller and lighter than alpha particles. They are subsequently more penetrating, but their rate of ionization is much less than that of alpha particles. The penetration range of beta particles depends on their energy and the density of the material they are passing through. An average-energy beta particle will not penetrate a thin sheet of metal and will only travel about 10 mm in tissue. Hence, beta-emitting radionuclides are a hazard to skin and eyes as well as a hazard if they are inhaled or ingested. Ease of detection of beta radiation depends on the energy level. However, all but the lowest energies can be detected fairly easily.

Gamma Radiation

Gamma radiation is electromagnetic radiation similar to radar, radio, TV, microwave, light, ultraviolet, and infrared radiation. However, gamma radiation has higher energy, higher frequency, and shorter wavelength than these similar forms of radiation. X-rays can be generally regarded as lower energy gamma rays that are machine-produced instead of stemming from a radioactive atom.

Gamma radiation can penetrate much further when compared to beta or alpha radiation. Consequently, it is relatively easy for gamma radiation to completely penetrate through the body. Gamma radiation is an external and internal hazard but can be shielded by dense materials such as lead, steel, or uranium. It is easily detected, even at very low levels.

Neutron Radiation

In addition to existing in the nucleus, it is possible to have free neutrons as a form of radiation. Neutrons are unique among the types of radiation in that they only have interactions with other

nuclei (nuclear reactions). Neutrons are very penetrating and the ease with which they can be shielded and detected depends heavily on their energy. They can cause significant cell damage as they pass through the body. They are an external and internal hazard but can be shielded by hydrogenous material (such as water) or materials including elements such as cadmium or boron. They are detected only with special instruments.

APPENDIX B THE Q-SYSTEM FOR THE CALCULATION OF A_1 AND A_2 VALUES

An important concept embedded in the International Atomic Energy Agency (IAEA) transport safety regulations [6] is the establishment of A_1 and A_2 values. These values determine the maximum quantity (activity) of a radionuclide that can be shipped in a package that is not designed to withstand a severe accident (Type A package).

The A_1 value is the activity limit based on radioactive materials in indispersible special form (encapsulated) where the main hazard is from direct exposure.

The A_2 value is the activity limit based on radioactive materials in normal form where the hazards can result from direct exposure, inhalation, ingestion, or submersion.

In the 1985 edition of its Transportation Safety Regulations (now called SSR-6), the IAEA developed the Q system to update the dosimetric models used in the derivation of Type A package contents limits. The goals were to develop more realistic accident scenarios and to strengthen the relationship between the transportation safety standards and internationally accepted radiation exposure limits. Since then, the Q-system has been the basis for calculating A_1 and A_2 values for individual radionuclides and mixtures of radionuclides. These limits, A_1 and A_2 , in addition to defining the content limits of a Type A package, are also used for several other purposes in the regulations, such as specifying package leakage limits, specifying the package limits for excepted quantities, low specific activity material, and surface contaminated objects.

The content limits of a Type A package, A_1 and A_2 values, are set to ensure that the radiological consequences of severe damage to a Type A package are acceptable, and design approval by the CNSC is not required, except for packages containing fissile material. Activities in excess of the Type A package limits must be transported in a package whose design requires CNSC approval (called a Type B package). The design requirements for Type B packages are designed to reduce the probability of a significant release of radioactive material or increased external dose during a severe accident to a level that would not significantly affect public health and safety.

The dosimetric Q system considers a series of exposure pathways (see Figure A-1 in Appendix A). In particular, it looks at pathways which might lead to radiation exposure, either external or internal, to persons in the vicinity of a Type A package involved in a severe transport accident. In evaluating the accident doses, the model assumes that 10^{-3} to 10^{-2} of a Type A package's content would be released in an accident, and 10^{-4} to 10^{-3} of the material released would be taken up by an individual. The model assumes that the individual would be exposed for 30 minutes at a distance of 1 meter.

The doses for individual radionuclides are evaluated for each of the exposure pathways to determine the A_1 and A_2 values for each scenario that would limit the doses to:

- Whole body effective dose less than or equal to 50 mSv
- Dose to individual organs less than or equal to 0.5 Sv
- Dose to eyes less than 0.15 Sv

The final A_1 value assigned to an individual radionuclide in special form is the greater of doses calculated for the external gamma and beta doses. This is because special form material is not dispersible, and the hazard consists solely of direct exposure. Radioactive material in normal form is considered as readily dispersible and therefore the A_2 value assigned to an individual radionuclide is based on the largest dose calculated for all exposure pathways.

The A_1 and A_2 values for individual radionuclides are listed in Section IV, Table 2 of SSR-6 [6]. An extract from Table 2 is reproduced in Figure B-1. The table illustrates the following points:

1. The activity that can be shipped in a Type A package for an individual radionuclide when as normal and special form. For example, for Americium-241 (Am-241), a Type A package is limited to 1×10^1 TBq when shipped as special form (indispersible) and 1×10^{-3} TBq as normal form (dispersible). Quantities greater than these must be transported in accident-resistant Type B packages.
2. For Am-241 to qualify as an exempt material, the activity concentration limit must not exceed 1×10^0 Bq/gram.
3. The total activity for all exempt packages in a consignment (shipment) for Am-241 must not exceed 1×10^4 Bq.

The A_1 and A_2 values are used to:

- Classify package contents based on form (normal or special), activity (quantity) and specific activity (concentration).
- Define package types and content limits for each classification of radioactive material.
- Define acceptance criteria for package evaluations under routine, normal and severe accident conditions.
- Limit the number of packages that can be shipped together.

Using the A_1 and A_2 values in this manner relates these activities directly to internationally-accepted radiation exposure limits.

TABLE 2. BASIC RADIONUCLIDE VALUES

Radionuclide (atomic number)	A_1 (TBq)	A_2 (TBq)	Activity concentration limit for exempt material (Bq/g)	Activity limit for an exempt consignment (Bq)
Actinium (89)				
Ac-225 (a)	8×10^{-1}	6×10^{-3}	1×10^1	1×10^4
Ac-227 (a)	9×10^{-1}	9×10^{-5}	1×10^{-1}	1×10^3
Ac-228	6×10^{-1}	5×10^{-1}	1×10^1	1×10^6
Silver (47)				
Ag-105	2×10^0	2×10^0	1×10^2	1×10^6
Ag-108m (a)	7×10^{-1}	7×10^{-1}	1×10^1 (b)	1×10^6 (b)
Ag-110m (a)	4×10^{-1}	4×10^{-1}	1×10^1	1×10^6
Ag-111	2×10^0	6×10^{-1}	1×10^3	1×10^6
Aluminium (13)				
Al-26	1×10^{-1}	1×10^{-1}	1×10^1	1×10^5
Americium (95)				
Am-241	1×10^1	1×10^{-3}	1×10^0	1×10^4

Figure B-1: Tabulation of A_1 and A_2 values from Table 2 of the IAEA's SSR-6 [6]

APPENDIX C MATERIAL CLASSIFICATIONS BASED ON LOW SPECIFIC ACTIVITY OR CONTAMINATION

As noted in Table 2-1 in Section 2.3.2, industrial packages are used to transport certain low specific activity (LSA) materials and surface contaminated objects (SCOs). There are three types of industrial packages (Type IP-1, Type IP-2, and Type IP-3) that are used for LSA and SCO shipments. Below is a simplified definition of the classes of LSA materials and SCO.

Low Specific Activity (LSA)

LSA materials are materials that have a low specific activity and in which the activity is uniformly distributed throughout. LSA material is considered a low hazard material because a person could not physically breathe in or ingest enough material to cause serious harm. As such, these materials are not shipped in package types that are designed to withstand severe accident conditions.

There are three classes of LSA materials:

LSA-I includes unirradiated natural or depleted uranium and thorium compounds and ores, and other radioactive material with unlimited A_2 values or with a specific activity which reaches only a very low level.

LSA-II includes water with a tritium concentration of up to 0.8 TBq/L and other material in which the activity is distributed throughout, and the estimated average specific activity does not exceed $10^{-4} A_2/\text{g}$ for solids and gases, and $10^{-5} A_2/\text{g}$ for liquids.

LSA-III includes solids (e.g., consolidated wastes, activated materials), excluding powders, in which the radioactive material is distributed throughout a solid or a collection of solid objects, or is essentially uniformly distributed in a solid compact binding agent (such as concrete, bitumen and ceramic) and the estimated average specific activity of the solid, excluding any shielding material, does not exceed $2 \times 10^{-3} A_2/\text{g}$.

Detailed requirements for LSA materials are outlined in paragraphs 408-411 of SSR-6 [6].

Surface Contaminated Object (SCO)

SCOs are solid objects that are not themselves radioactive, but which have radioactive material in the form of non-fixed contamination distributed on their surface. The hazard associated with these materials arises from surface contamination that can be scraped off in an accident. Like LSA materials, SCOs are considered a low hazard material because a person could not physically breathe in or ingest enough material from an accident to cause serious harm. As such, SCOs are not shipped in package types that are designed to withstand severe accident conditions.

There are three classes of SCOs:

SCO-I material includes solid objects which have the lowest levels of non-fixed contamination, fixed contamination, and non-fixed plus fixed contamination. Examples of these could include large items associated with decommissioning of nuclear plants, such as building rubble, structural steelwork, pipes, machine tools and other scrap.

SCO-II material includes solid objects on which either the fixed or non-fixed contamination on the surface exceeds the applicable limits specified for SCO-I and on which objects have the highest levels of fixed, non-fixed, and non-fixed plus fixed among both categories. Examples of these could include equipment and decommissioning wastes, described earlier, when the contamination level exceeds the values authorized for SCO-I. They must also comply with the other requirements for SCO-II.

SCO-III material includes large solid objects that cannot be transported in a type of package described in SSR-6 due to their size. The openings must be sealed, the inside must be dry and specific contamination limits must be met.

Detailed requirements for SCO materials are outlined in paragraphs 412-414 of SSR-6 [6].

APPENDIX D REGULATORY REQUIREMENTS BASED ON CONDITIONS OF TRANSPORT

As described in Section 2.3.1, a graded approach is applied to the regulatory requirements for transportation packages based on the conditions of transport. All radioactive materials are subject to general requirements. In addition, the following severity levels are applied according to the package type:

- (a) Routine conditions of transport (incident free)
- (b) Normal conditions of transport (minor mishaps)
- (c) Accident conditions of transport

Table D-1 presents the applicability of general requirements under routine conditions of transport for each package type. General requirements are provided in paragraphs 607-618 of SSR-6 and additional requirements for air transport are provided in paragraphs 619-621 of SSR-6 [6].

Table D-1: General design requirements for all packages under routine conditions of transport

	EXCEPTED PACKAGE	IP-1	IP-2	IP-3	TYPE A	TYPE B	TYPE C
General Requirements							
As they relate to:							
Handling, lifting, protrusions, water retention, vibrations, acceleration for routine conditions of transport, ageing mechanisms, material compatibility, valves, ambient temperature, and pressure, shielding	X	X	X	X	X	X	X
Additional Requirements for Air Transport							
As they relate to:							
Temperature and pressure	X	X	X	X	X	X	X

Table D-2 presents the applicability of test requirements under normal conditions of transport for each package type. Package test requirements for normal conditions of transport are provided in paragraphs 719-725 of SSR-6 [6].

Table D-2: Package tests requirements for normal conditions of transport

	EXCEPTED PACKAGE	IP-1	IP-2	IP-3	TYPE A	TYPE B	TYPE C
Drop test 0.3-1.2 m			x	x	x	x	x
Stacking			x	x	x	x	x
Water Spray				x	x	x	x
Penetration							
1.0 m				x	x	x	x
1.7 m					Liquids Gases		

Table D-3 presents the applicability of test requirements under accident conditions of transport for each package type. Package test requirements for accident conditions of transport are provided in paragraphs 726-737 of SSR-6 [6]. Note that the drop/crush test, penetration and thermal tests must be done on the same specimen in the most damaging orientation.

Table D-3: Package test requirements for accident conditions of transport

	EXCEPTED PACKAGE	IP-1	IP-2	IP-3	TYPE A	TYPE B	TYPE C
Drop Test 9 m					Liquids Gases	HHD ¹	x
Penetration 1 m						x	
Crush Test 9 m						LLD ²	x
Thermal Test						x	
Water Immersion 15 m						x	x
Water Immersion 200 m						LQ ³	x
Puncture-Tearing Test							x
Enhanced Thermal Test							x
Impact Test							x
Water Leak Test for Criticality	All packages that contain fissile material						
Notes: 1. High Weight/High Density Package 2. Light Weight/Low Density Package 3. Large Quantity Packages (> 10 ⁵ A ₂)							

Finally, Table D-4 displays the graded approach applied to all radioactive material packages.

Additional details regarding the requirements are provided in SSR-6 [6].

Table D-4: Graded approach to radioactive material packages

	EXCEPTED PACKAGE	IP-1	IP-2	IP-3	TYPE A	TYPE AF	TYPE B	TYPE BF	TYPE C
Air Accident Conditions									X
+ Fissile								X	
Accident Conditions							X	X	X
+ Fissile						X		X	
Normal Conditions			X	X	X	X	X	X	X
Routine Conditions	X	X	X	X	X	X	X	X	X
SSR-6 Paragraphs	607-618	607-618 636	607-618 636 722-723	607-618 636-649 722-723	607-618 635-651	607-618 635-651 673-675	607-618 636-649 ¹ 653-666	607-618 636-649 ¹ 653-666 673-675	607-621 636-649 ¹ 653-657 661-666 670-672

¹ Except as specified in paragraph 648(a)

APPENDIX E ADDITIONAL INFORMATION ON TESTING METHODS

As described in Section 3.3, testing to demonstrate Type B package compliance with regulatory requirements can be performed using full-scale physical testing, scaled physical testing, computer modelling, and/or calculations. The choice of method for each test is determined by several factors which are discussed in this appendix. Information on the methods is provided in Appendix E.1 to E.3 and the use of each method for each regulatory test is described in Appendix E.4.

E.1 PHYSICAL TESTING

Physical testing is a common method of assessing package design performance and has been utilized in many countries with used nuclear fuel transportation programs. Testing of Type B package designs is typically conducted in designated testing facilities which feature the capability for testing packages weighing upwards of 100 tonnes. Physical testing can be performed with full-scale models (see Appendix E.1.1) or scale models (see Appendix E.1.2). Testing facility characteristics are discussed in Appendix E.1.3.

Physical testing may also be utilized for a variety of reasons beyond just verification of design, verification of fabrication, and inspection methods. Physical testing also provides validation of values which can be used to enhance computer modelling. Moreover, the documentation of these physical tests during the licensing process (i.e., pictures and videos) is also used as safety demonstrations to provide the public with a visual demonstration of the safety of the Type B packages. A list of various physical tests across the world and their specifics are found in Section 4.

E.1.1 Full-Scale Physical Testing

The most common full-scale physical tests conducted are the *Free-Drop Test* and *Puncture Test* as the setup requirements are straightforward, and containment integrity following the tests can be validated via a standardized leak test. The *Thermal Test* has also been conducted on full-sized packages, whether through the use of controlled burns or utilizing large industrial ovens to achieve similar heat flux conditions. Additional information on the test methods used for each regulatory test is provided in Appendix E.4.

E.1.2 Scale Model Physical Testing

The *Free-Drop* and *Puncture* tests are often performed with scale models to facilitate package handling, facility capabilities, and the ability to perform the tests using multiple orientations to determine the sequence that results in the package suffering maximum damage. Scale model testing is a proven and accepted practice across engineering disciplines, including for testing airplanes, ships, buildings, and other large engineered structures. SSR-6 permits scale models to

be used if appropriate adjustments to certain parameters are accounted for. Table E-1 outlines the testing outputs that may be obtained from scale model testing.

Table E-1: Parameters gained from scale model testing

Aims of Tests	Use of Scale Models
Quantification of stresses and deformations	Recommendable
Verification of calculations (methods, models)	
Identification of construction weak points	
Stresses and Strains	
Acceleration	
Bolt Forces	
Design verification	Achievable, with additional setup and test methods
Verification of manufacturing and inspection methods (with test specimen first)	
Quantification of leakage rates	

For impact tests (e.g., *Free-Drop Test and Puncture Test*), the scale model must be made of identical materials as specified for the package design. Additionally, the drop conditions (i.e., the drop height, velocity and orientation angle) must be identical to that which would be used in a full-scale physical test. The scale model must have only one independent scaling factor – this means that, for example, a scale model cannot scale some parameters to a 1/2 scaling factor and others to a 1/3 scaling factor. Additional details for designing scale model tests are provided in *Guidelines for Conducting Impact Tests on Shipping Packages for Radioactive Material* [85]. The *Thermal Test* is not conducted with scale models because the input and output variables cannot be scaled accurately.

As discussed above, scale model tests must have one independent scaling factor. Based on this scaling factor, the output values (i.e., the information that the test is designed to provide) can be determined based on scaling relationships. These scaling relationships are well understood and firmly based on the equations of physics [86]. Table E-2 compiles the scaling relationships for various values that scale model tests are typically designed to measure.

Table E-2: Values obtained by scaling factors

Scaling Factor of Test	Values Measured
Full-Scale	Impact Velocity, Pressure, Density
Scale with Scaling Factor	Length, Time, Deformation
Scale with Inverse of Scaling Factor	Acceleration, Strain Rate
Scale with Square of Scaling Factor	Force, Area
Scale with Cube of Scaling Factor	Mass, Volume, Energy, Moment

Parameters that introduce challenges to scale model testing include scaling small package components (fabrication may not be possible at a scaled size) and elastomeric seals. Components may not be available at exact scaling factors, whereupon conservative component scaling must be exercised. For these cases, the adequacy of scale model testing is to be confirmed experimentally or with computer modelling. If confirmed experimentally, the test could be performed with different independent scaling factors and compared to ensure they correlate using established scaling laws. Computer modelling can be used to confirm that the scale model tests consider all parameters controlling the results. Additionally, different scale model tests can be used to demonstrate the performance of different package components.

Regarding the scaling of elastomeric seals and package leak rates, many factors must be considered to predict leakage rates on the basis of scale model test results [24]. Adequate safety factors must also be used for scale model testing of package leakage rates and often a combination of test methods may be the most efficient way to demonstrate compliance with leakage rate limits. Additional information is provided in *Application of Leakage Rates Measured on Scaled Cask or Component Models to the Package Containment Safety Assessment* [87].

E.1.3 Testing Facility Characteristics

Around the world, there exist testing facilities specifically designed to test Type B packages. However, each facility may have been constructed with different goals or characteristics in order to conduct physical testing safely and accurately. The testing facility should maintain a controlled environment with appropriate certified testing equipment, such as drop towers, dynamometers or pendulum impact testers, to simulate real-world transportation scenarios. The International Atomic Energy Agency's (IAEA) SSG-26 document provides design guidance for testing facilities [24].

BAM operates a drop test facility in Horstwalde, Germany [88]. The BAM drop test facility was constructed in 2004 for performing drop tests of full-scale packages up to a total mass of 200 000 kg. Figure E-1 shows a Type B package being subjected to the 9 m drop test at the BAM drop test facility. The main construction features are:

- 36 m high drop tower as steel pipe construction.

- 200 ton hoist on top of the drop tower, with a maximum hook height of 30 m.
- A 24 m x 20 m closed test hall below the drop tower with moveable roof and rolling gates.
- An 80 ton overhead crane inside the test hall.
- The unyielding target is realized by a reinforced concrete block with the dimension 14 m x 14 m x 5 m depth, with a mass of 2,450,000 kg, and with an impact pad made of anchored mild steels plates 10 m x 4.5 m x 0.22 m.

The impact pad consists of a center steel plate 2.5 m x 10 m x 0.22 m and two side steel plates 1.0 m x 10 m x 0.22 m, also embedded and fixed on the concrete block.



Figure E-1: Full-scale 9 m drop testing at the BAM drop test facility

Canada previously operated testing facilities at Chalk River Laboratories in Deep River, Ontario. A special facility was designed to conduct the *Free-Drop*, *Puncture* and *Thermal* tests. The facility had been used to conduct drop tests in the past on a half-scale model of the UFTP. Images of these tests are shown in Figure E-2.

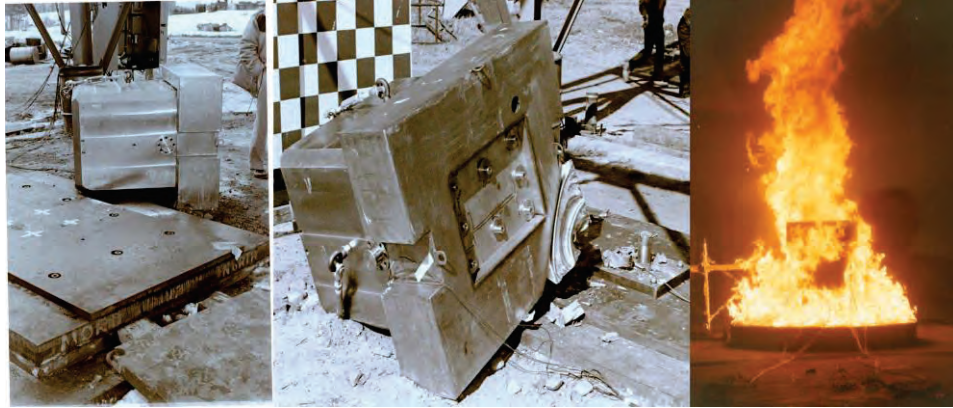


Figure E-2: Impact and thermal tests on the UFTP at the Chalk River Laboratories testing facility

E.2 COMPUTER MODELLING

Although the IAEA SSR-6 packaging standards are described as physical tests, the standards allow alternative methods to demonstrate compliance. These alternative methods include calculations such as computer modelling (IAEA's SSR-6, Paragraph 701). Computer modelling can be applied to simulate and predict the behavior of a package under various conditions, such as during transportation or in the event of an accident. The analysis models represent the complete package, including the impact limiters, the package body, the contents and any overpacks. All of these items are explicitly modelled in three dimensions.

For *Impact and Immersion Tests*, structural analysis can be performed using computer modelling (e.g., with the use of Finite Element Analysis (FEA)). FEA is a method that uses computation to simulate how an object would behave under various physical conditions, such as the conditions experienced during an *Impact or Immersion Test*. A major advantage of using computer modelling is that it allows the package to be analyzed for many different drop angles to determine the most damaging orientation, especially for large packages where it may be impracticable to conduct multiple physical drop tests. Advancements in computational modelling and the use of conservative values and code margins for design features have supported the use of computer modelling for *Impact and Immersion Tests*. The factors of safety (i.e., how much margin for the calculation) should be selected and justified by the package designer, with acceptance by the competent authority, taking into account confidence in the validation of methods used and uncertainties. Verification and validation of codes is discussed in Appendix E.2.1.

Computer modelling can also be used to perform or confirm the *Thermal Test*. Computer modelling is typically completed using Computational Fluid Dynamics (CFD) which uses numerical methods to simulate the behaviour of liquids and gases, such as the behaviour of fire and air during the *Thermal Test* conditions. Fire parameters are modelled according to the regulations and the heat flux is applied as would be the case in a physical test.

Computer modelling for testing package leakage rates is not typically performed given the challenges associated with modelling the properties and behaviour of elastomeric seals in Type B packages.

Computer modelling can also be used to optimize the package design, identify potential issues and vulnerabilities, and inform improvements to the package's safety and efficiency. Computer modelling is a useful tool for enhancing the safety and effectiveness of transport packages.

Margins of error are used in computer modelling to ensure that results are conservative – this means that in many cases, results from computer modelling exceed the minimum safety requirements in the regulations and have a bigger design safety factor than results from physical testing can provide. The safety margins represent the degree to which a package's design, and its performance during testing, exceed the minimum safety requirements as laid out in the regulations.

E.2.1 Verification and Validation of Computer Codes

Computer codes are validated for their intended uses and verified prior to their use. Based on the definitions provided in CSA N286.7-16, *Quality assurance of analytical, scientific, and design computer programs* [89], *verification* is the process of determining whether or not the computer code fulfills the applicable requirements. *Validation* meanwhile is the process to assess fitness and quantify computer code accuracy for its intended applications. Validation is performed by comparing results calculated using the computer code with relevant measured data or known solutions.

E.3 COMBINED USE OF COMPUTER MODELLING AND PHYSICAL TESTING

Using computer modelling has proven to yield reliable results, even for dynamic impacts. As with all computer modelling methods, it is imperative that the modelling be conducted in accordance with appropriate materials/material laws and contact parameters. While the regulations allow for the use of computer models to demonstrate the safety of a design, reliable physical tests can be used to supplement information that is harder to extract from computer models.

Developing force-deflection curves for a package impact limiter and target is a challenge in computer modelling but can be obtained through physical tests or analyses. Computer modelling should be used if impact loads are near limits, based on real material properties from physical testing.

E.4 METHODS COMMONLY USED FOR EACH REGULATORY TEST

The following subsections describe the methods commonly used for each regulatory test. Regardless of the method used, documentation should be sufficiently accurate and complete to allow an approving authority (i.e., the Canadian Nuclear Safety Commission in Canada) to determine that all safety requirements have been met and all modes of failure considered. In practice, a package design for used fuel typically uses a combination of computer modelling, scale model testing and full-scale mock-ups of package components. It is up to the applicant to choose the appropriate methods for each regulatory test and up to the approving authority to verify that the selected methods are appropriate.

E.4.1 Impact Tests

While physical testing is often used to verify results, computer modelling is often used as the first step in the assessment. This is due to it being more efficient and the ease of testing the same package in different scenarios without having to build a new package every time it is damaged. Computer modelling makes it easier to find the most damaging orientation by testing impacts at various locations on the package and various package orientations. When computer analysis is done, it is verified that the solution method is appropriate for the evaluation and that the computer program used to conduct the analyses is reliable. When using these methods, the solution methods, benchmarking results and quality assurance program for maintaining and using the computer codes is documented and submitted for approval.

While computer modelling is more practical than physical testing, it often requires additional full-scale or scale model testing to analyse the force-deflection curve of the impact limiter. The dynamic response of O-rings during an impact test also may not be accurately modeled by computer analysis as the O-ring fits into a groove formed by the package and lid surfaces. The O-ring groove may not have totally smooth surfaces which may result in multiple small leak paths between the O-ring and groove surfaces. To assure that the O-ring maintains a proper seal, a physical leak test has to be done on the O-rings during certification testing to show that the package can meet the regulatory requirements for containment.

E.4.2 Thermal Test

The *Thermal Test* can be performed using either computer modelling or physical testing, or by a combination of both. Physical testing of the *Thermal Test* is difficult since it requires a large amount of fuel (to sustain the fully engulfing fire), intricate instrumentation, and ambient wind conditions. Only a few specialized facilities are available that can do these tests for large packages, such as a UNF package. Due to this, computer modelling (often using Computational Fluid Dynamics (CFD)) is used most of the time. The use of computer modelling for the *Thermal Test* also allows a margin of safety to be applied. Scale model testing is not used for the *Thermal Test* for the purposes of certification by a competent authority.

E.4.3 Immersion Tests

The *Immersion Tests* are most often conducted using computer modelling as it is the most cost effective and the data/variables can be obtained and controlled easily. The effects of increased pressure on package materials are well understood and computer modelling software is capable of effectively assessing the package performance.

APPENDIX F PACKAGES USED FOR USNRC ACCIDENT RECONSTRUCTIONS

F.1 HOLTEC HI-STAR 100 SNF TRANSPORTATION PACKAGE

The HI-STAR 100 is a Type B package designed to ship used fuel by rail. The design (Figure F-1) features an outermost containment boundary in the form of the package shell, lid and lid seals. It provides an additional containment boundary in the form of a welded multi-purpose canister (MPC) enclosing the used fuel. Holtec uses MPC designs to accommodate three different used fuel loading configurations: up to 24 PWR assemblies, up to 32 PWR assemblies, or up to 68 boiling water reactor (BWR) assemblies.

The package inner shell is stainless steel, and six layers of carbon steel plates comprise the gamma shield. The next layer is a polymeric neutron shield, strengthened by a network of carbon steel stiffening fins. The outer shell of the package is carbon steel, with a painted surface. Aluminum honeycomb impact limiters with stainless steel skin are installed on the ends of the package prior to shipping. These impact limiters protect the closure lid, MPC, fuel basket, and contents from damage in the event of a package drop accident. The impact limiters also provide thermal insulation to the lid and port cover components in the event of a fire exposure. This package weighs approximately 277 300 lbs (125 781 kg) when loaded for transport.

The MPC-24 configuration was selected for the Baltimore Tunnel fire study. This configuration of design has an integral fuel basket that accommodates 24 PWR used fuel assemblies with a maximum total decay heat load of 68 240 BTU/hr (20 kW). The MPC is placed in the transportation packaging for shipment after it has been loaded with used nuclear fuel and welded shut.

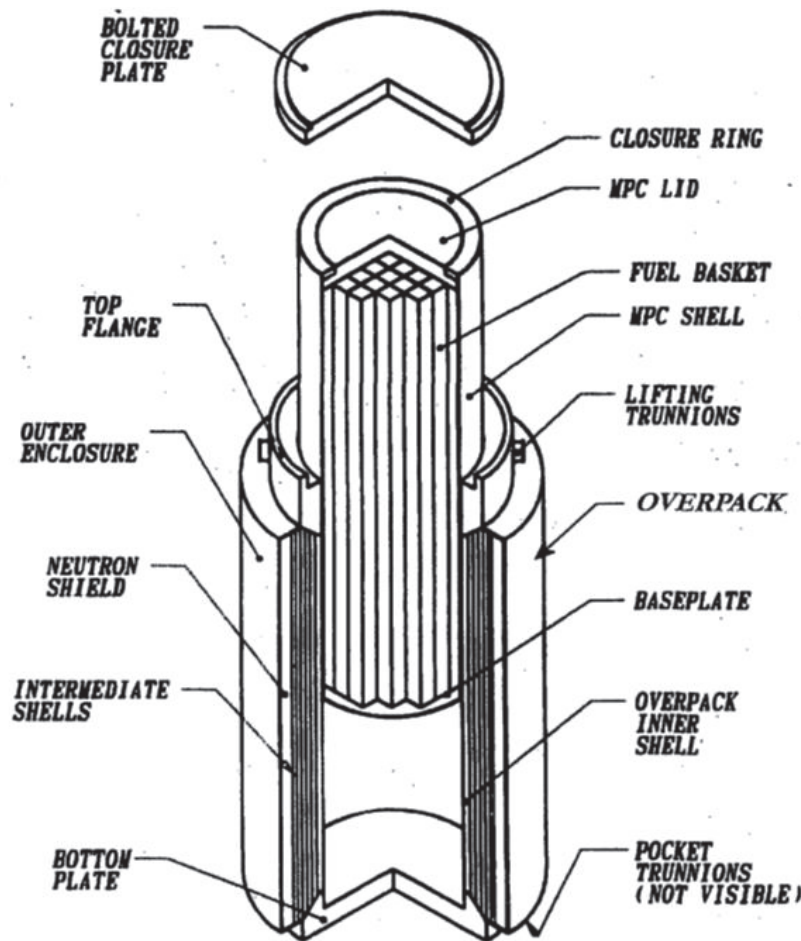


Figure F-1: Exploded view of the Holtec Hi-Star 100

F.2 TRANSNUCLEAR TN-68 TRANSPORTATION PACKAGE

The TN-68 is a Type B package used to ship BWR used fuel assemblies (Figure F-2) by rail. The basic design is similar to that of the Holtec HI-STAR 100, except that the TN-68 package does not include an inner seal-welded canister.

The containment boundary is provided by the package shell and lid seals. The TN-68 package holds up to 68 BWR assemblies, with a maximum total decay heat load of 72 334 BTU/hr (21.2 kW). The fuel assemblies are contained within a basket structure consisting of 68 stainless steel tubes that have aluminum and borated aluminum (or boron carbide/aluminum composite) neutron poison plates sandwiched between the steel tubes. The basket structure is supported by aluminum alloy support rails bolted to the inner carbon steel package shell, which also serves as the inner gamma shield. This inner steel shell is shrink-fitted within an outer carbon steel shell that serves as the outer gamma shield. The gamma shielding is surrounded by the neutron shielding, which consists of a ring of aluminum boxes filled with borated polyester resin.

The outer shell of the package is carbon steel. The package bottom is carbon steel with an inner steel shield plate. The package lid is also carbon steel with a steel inner top shield plate. During transport, the ends of the package are capped with impact limiters made of redwood and balsa and covered in stainless steel plate. The TN-68 weighs approximately 260 400 lbs (118 115 kg) when loaded for transport.

The TN-68 was one of the three packages used to evaluate the potential effects of an accident of the magnitude and severity of the Baltimore Tunnel Fire.

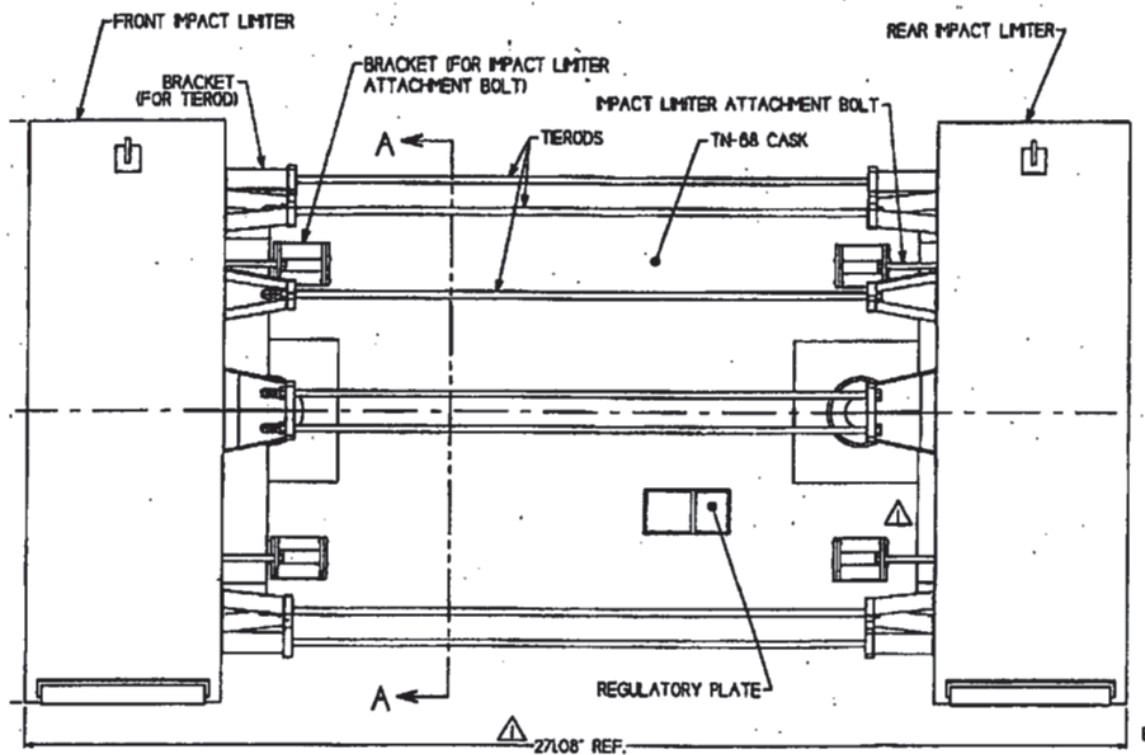


Figure F-2: Engineering drawing of the TN-68 transportation package

F.3 NAC-LWT TRANSPORTATION PACKAGE

The NAC-LWT (Figure F-3) is a Type B package certified for transport on a standard tractor trailer truck, and which can also be transported by rail. The NAC-LWT is typically enclosed within an International Organization for Standardization (ISO) shipping container when shipped by rail. This package is designed to transport a variety of commercial and test reactor fuel types with widely varying maximum decay heat load specifications. For the purpose of the Baltimore Tunnel study, the package was assumed to contain a single PWR used nuclear fuel assembly, with a maximum decay heat load of 8 530 BTU/hr (2.5 kW). The loaded package weighs approximately 52 000 lbs (23 586 kg).

The containment boundary provided by the stainless-steel package consists of a bottom plate, outer shell, upper ring forging, and closure lid. The package has an additional outer stainless-steel shell to protect the containment shell, and also to enclose the lead gamma shield. Neutron shielding is provided by a stainless-steel neutron shield tank containing a water/ethylene glycol mixture. An additional annular expansion tank for the mixture is provided, external to the shield tank. This component is strengthened internally by a network of stainless-steel stiffeners. Aluminum honeycomb impact limiters covered with an aluminum skin are attached to each end of the package.

The NAC-LWT package was also used to evaluate the potential effects of the Caldecott Tunnel Fire.



Figure F-3: NAC-LWT transportation package on display

F.4 GA-4 LEGAL WEIGHT TRUCK TRANSPORTATION PACKAGE

The General Atomics GA-4 legal weight truck (LWT) Type B package can carry a relatively large payload for a legal weight truck package, and therefore the potential consequences of package failure could be more severe than for packages with smaller payload capacities. The GA-4 package is designed to transport up to four intact PWR used fuel assemblies with a maximum decay heat load of 2 105.4 BTU/hr (0.617 kW) per assembly, for a total package decay heat load of 8 423 BTU/hr (2.468 kW). The GA-4 can carry zircaloy-clad UO_2 fuel with maximum initial enrichment of 3.15% U-235, in 14x14 assemblies with maximum average burnup of 35 GWd/MTU (minimum cooling time of 10 years), or 15x15 assemblies with maximum average burnup of 45 GWd/MTU (minimum cooling time of 15 years).

The stainless-steel package body encloses the gamma shield, which consists of an inner shell of depleted uranium (DU). Neutron shielding is provided by a stainless-steel neutron shield tank external to the package body, containing a water/propylene glycol mixture. Aluminum honeycomb impact limiters, completely enclosed in a thin stainless steel outer skin and inner housing, are attached to each end of the package.

This transportation package (Figure F-4) was selected to evaluate the potential effects of an accidents of the magnitude and severity of the Newhall Pass Tunnel and MacArthur Maze fires on an NRC-certified UNF Type B transportation package.

For the purpose of the Newhall Pass Tunnel fire analysis, the package was assumed to contain four Westinghouse Electric 14x14 PWR used nuclear fuel assemblies at the maximum decay heat load. The payload capacity is 6 648 lbs (3 015 kg), and the fully loaded package weighs approximately 55 000 lb. (24 948 kg). The package containment boundary is provided by the stainless-steel package body wall, the stainless-steel bottom plate, the stainless-steel package closure lid secured by Inconel fasteners and dual O-ring seals for the closure lid, gas sample port, and drain valve.

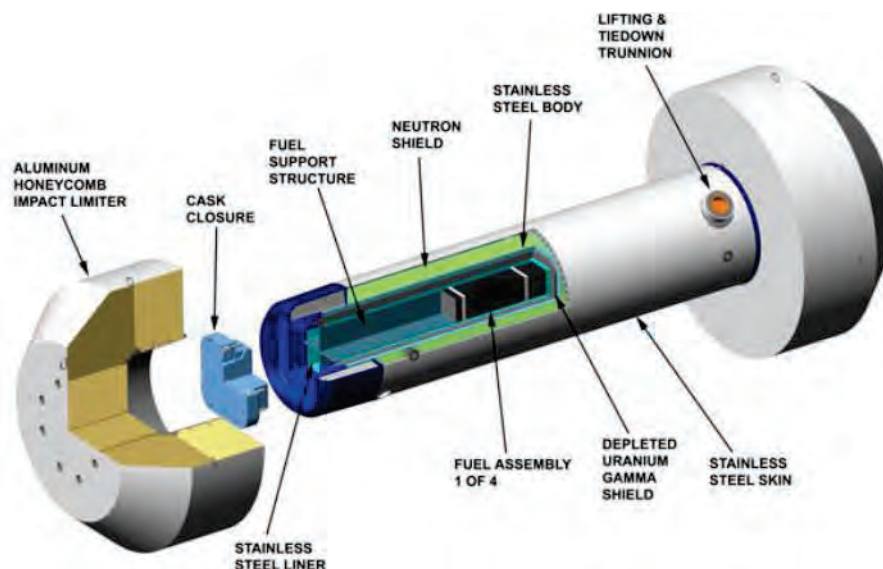


Figure F-4: Exploded view of the GA-4 legal weight truck transportation package

APPENDIX G SURVEY OF SEVERE CANADIAN ACCIDENTS (1979-2022)

Location	Date	Type	Deaths	Dangerous Goods		Number of Vehicles		Notes
				Good	Released (liters)	Train Total	Derailed	
Mississauga, ON [90], [91], [92]	1979	Train Derailment (72 km/h)	0	Caustic Soda Propane Styrene Toluene Chlorine	Release occurred from all derailed tank cars, except for one toluene tank car	3 locomotives 106 railcars	24 railcars Caustic soda (4) Propane (12) Styrene (3) Toluene (3) Chlorine (2)	Three propane tank cars exploded. Fires lasted 48 hours. Chlorine gas was released causing major evacuations.
Hinton, AB [93]	1986	Train Collision/ Derailment (95 km/h freight train, 79 km/h passenger train)	23	Caustic Soda Ethylene dichloride	None	3 locomotives 114 railcars 1 caboose	35 grain cars 7 flat bed - (pipe) 45 hopper cars (Sulphur)	Fire was fueled by the spilled locomotive diesel oil. Fire engulfed the lead units of each train, the baggage car and day coach. On Train 413 the 3 diesel locomotives, the high-speed spreader, 35 grain hopper cars, 7 flat cars carrying large pipes and 33 hopper cars carrying sulphur were destroyed or damaged.

Location	Date	Type	Deaths	Dangerous Goods		Number of Vehicles		Notes
				Good	Released (liters)	Train Total	Derailed	
Lac Mégantic, QC [94], [95]	2013	Train Derailment (105 km/h)	47	Crude Oil	6 000 000	72 tank cars 1 boxcar 5 locomotives 1 caboose	63 tank cars (DOT Class 111) 1 box car	40 buildings destroyed, 2000 people evacuated.
Gladwick, ON [96]	2015	Train Derailment (61 km/h)	0	Crude Oil (68 tank cars) Petroleum Distillates (32 tank cars)	1 700 000	100 railcars 2 locomotives	29 tank cars (19 breached)	Crude oil pooled and ignited. 19 tank cars were breached in the initial derailment. 5 tank cars subsequently suffered thermal tears. Fires burned for 5 days.
Gogama, ON [97]	2015	Train Derailment (69 km/h)	0	Crude Oil	2 600 000	94 tank cars 2 locomotives	39 tank cars (TC/DOT Class 111, CPC-1232) (33 breached)	33 tank cars were breached and released crude oil. Fire reached about 275 meters in diameter.
St. Lazare, MB [98]	2019	Train derailment (79 km/h)	0	Crude Oil	815 000	108 tank cars	37 tank cars (TC/DOT Class 117R) (17 breached)	Following the derailment, crude oil pooled near a culvert on the north side of the rail line. No fire.

Location	Date	Type	Deaths	Dangerous Goods		Number of Vehicles		Notes
				Good	Released (liters)	Train Total	Derailed	
Emo, ON [99]	2020	Train derailment (71 km/h)	0	Crude Oil	319 731	144 freight cars	29 tank cars (Mix of TC/DOT Class 111, CPC- 1232, and DOT 117 R) 28 crude oil 1 asphalt 4 non-DG (8 breached)	No fire reported.
Guernsey, SK [100]	2020	Train derailment (67 km/h)	0	Crude Oil	1 200 000	108 cars	32 tank cars DOT 117J100- W (19 breached)	Following the derailment, crude oil pooled and caught fire.

APPENDIX H POTENTIAL HAZARDS FROM BREACH OF A TANK CAR TRANSPORTING DANGEROUS GOODS

Most severe transport accidents in Canada involved the rupture (breach) of tank cars carrying flammable liquids. Two examples are the 1979 Mississauga and 2013 Lac Mégantic accidents. This appendix briefly describes the ways that tank cars fail in rail accidents and the consequences of such failures. For context, a comparison is made between the characteristics of shipments of flammable dangerous goods by tank car shipments and UNF shipments.

H.1 DANGEROUS GOODS SHIPPED IN TANKS CARS

Table H-1 shows the characteristics of several dangerous goods that are commonly shipped in tank cars, along with the characteristics of used fuel and radioactive material. The primary accident hazards in shipping these dangerous goods in tank cars are fire, explosion and release of toxic chemicals from tank car containment failure.

Table H-1: Characteristics of some dangerous goods

Type	Shipment Frequency	Physical Form	Primary Hazard(s)	Dangerous Goods Class
Gasoline	High	Liquid	Fire, Explosion	Class 3
Chlorine	High	Gas	Poison, Inhalation	Class 2.3 Class 8
Flammable Gas	High	Gas	Fire, Explosion	Class 3
Flammable Liquid	High	Liquid	Fire, Explosion	Class 3
Diesel Fuel	High	Liquid	Fire, Explosion	Class 3
Used Nuclear Fuel	Low	Solid	Radiation Exposure	Class 7
Radioactive Material	Low	Solid	Radiation Exposure	Class 7

As Table H-1 shows, there are numerous types of dangerous goods that are commonly shipped as flammable liquids or gases. For example, the Lac Mégantic accident involved shipping large quantities of flammable liquids, and the primary hazard in the Mississauga accident was the rupture of a chlorine tank car. A significant release of dangerous goods that are in liquid or gaseous form can occur if the tank car is breached or ruptured.

H.2 FAILURE MODE FOR TANK CARS IN ACCIDENTS

The various ways that a tank car can rupture are shown in Figure H-1. Although these illustrations (taken from the Lac Mégantic accident) are for U.S. Department of Transportation (DOT) Class 111 tank cars, they are typical for most other tank car types. The breaches fall into two major categories

involving either the failure of the tank car inlet and outlet or a breach in the tank wall. Some of the breaches, such as the failure of the inlet/outlet valves, cause slow or moderate leaks resulting in the pooling of flammable liquids and subsequent fire or vapor detonation explosions. The wall of the tank car can be breached by puncture, burn-through or a thermal tear. Thermal tears can involve a more rapid release as a result of BLEVE.

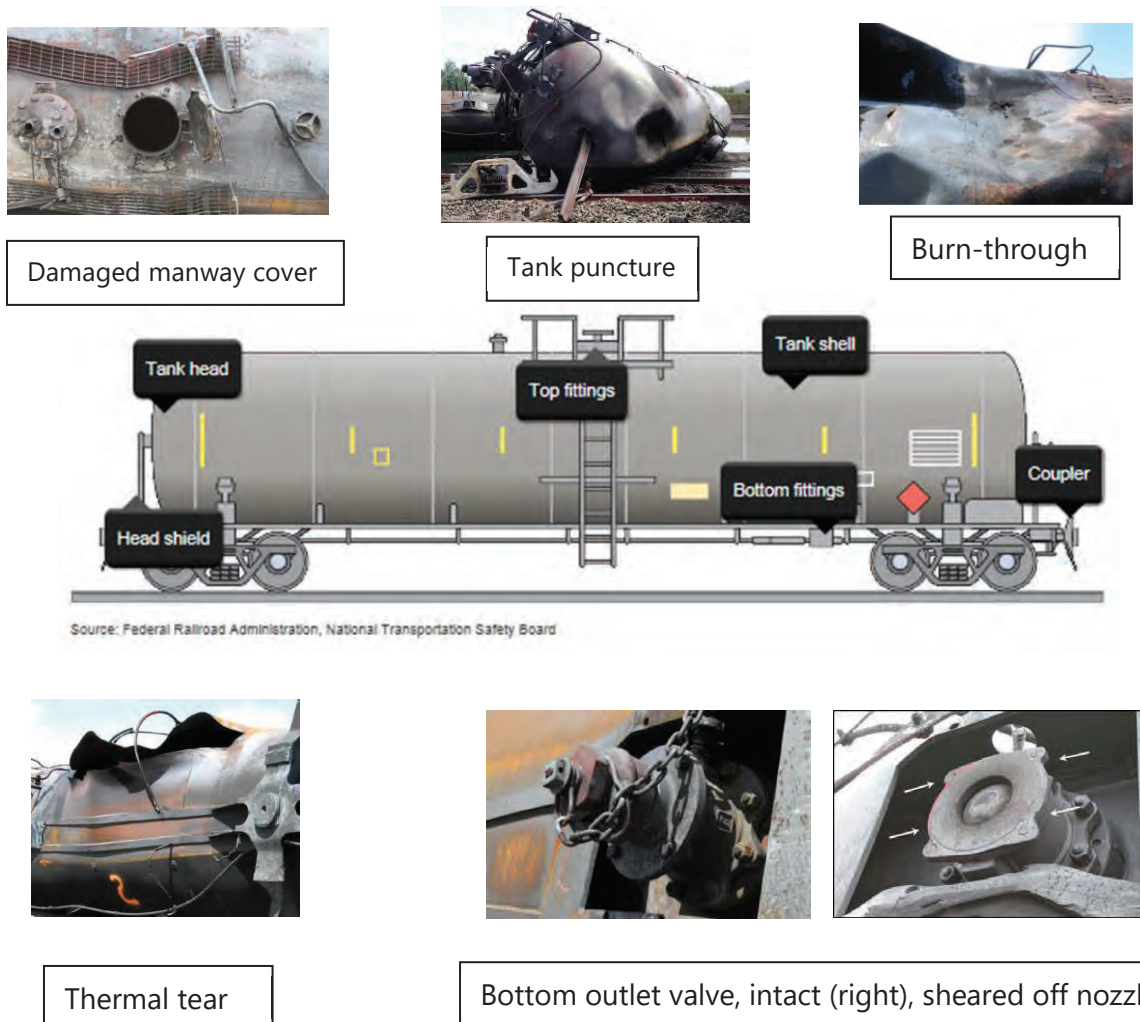


Figure H-1: Rupture modes for DOT class 111 tank cars

H.3 CONSEQUENCE OF A TANK CAR FAILURE

The consequences of a tank breach can vary for each tank car, depending on the type of breach. Figure H-2 shows the possible pathways that accidents involving a breach can follow. The most severe consequences result from BLEVEs, vapor cloud detonations (VCDs) and severe pool fires.

A BLEVE results in a tank car being burst apart, and can cause large tank fragments to be ejected at high speeds. The potential impact of a BLEVE on a UNF package was demonstrated in 1999 by

the German Federal Institute for Materials Research and Testing (BAM) using a tank car with liquified propane gas that BLEVEs next to a CASTOR used fuel package (see Section 4.4.1 of the report). BAM demonstrated that a UNF package could withstand the shockwave from a BLEVE with very little damage. VCDs are explosions that have blastwaves that are generally of the same order of magnitude as those occurring in a BLEVE. The main difference between a VCD and a BLEVE is that no tank fragments are ejected in a VCD as the explosion occurs external to the tank car. The potential impact of a pool fire on a UNF package depends on many variables, such as temperature, duration and location of the fire, position of the UNF package within the fire, mass (i.e., thermal inertia) of the package, and design of the lid sealing area or welded closure area.

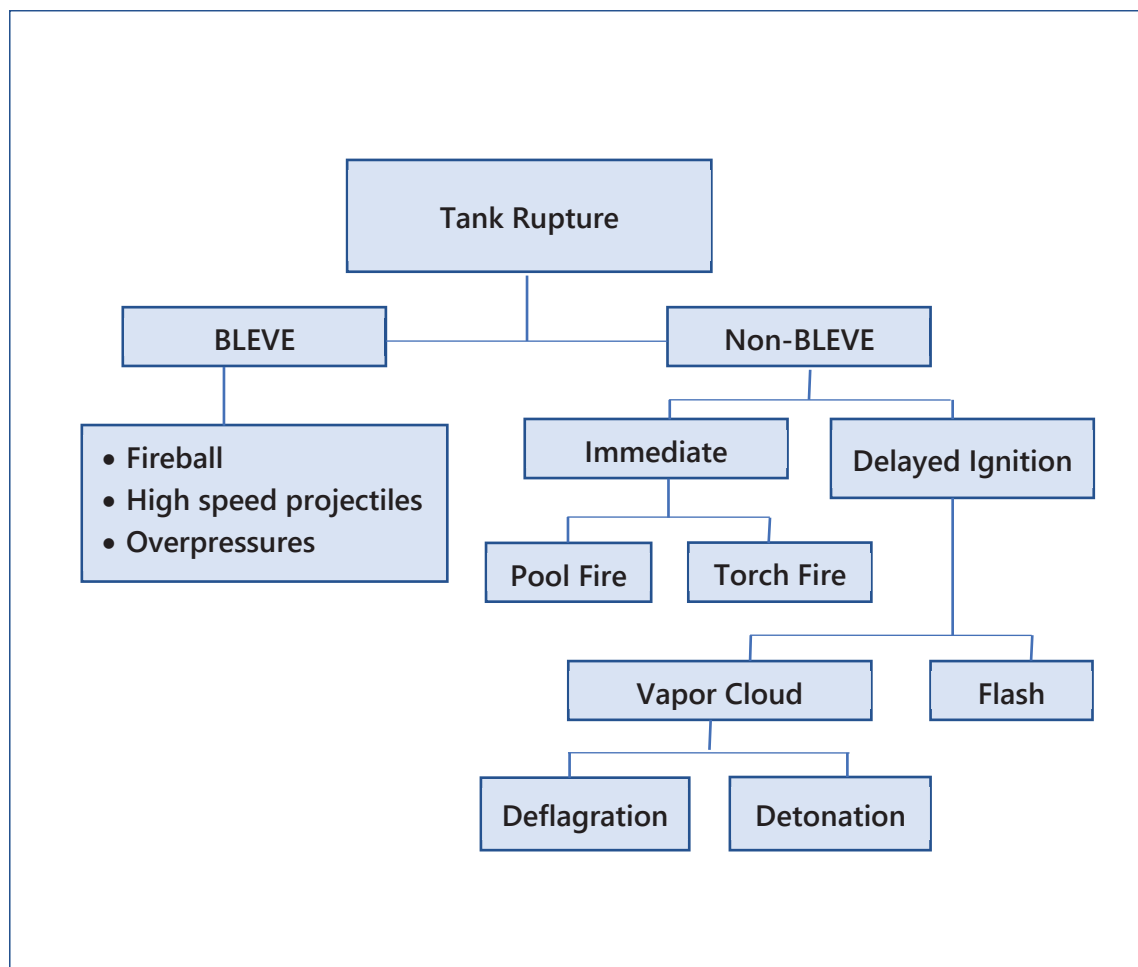


Figure H-2: Accident pathways resulting from the rupture of tank car

H.4 COMPARISON OF SHIPMENTS MADE IN TANK CARS VERSUS UNF SHIPMENTS

Figure H-3 shows a comparison of the characteristics of a shipment of a flammable liquid or gas made in a tank car versus the shipment of UNF made in a Type B package.

Flammable liquids and gases are frequently shipped in tank cars with relatively thin walls ranging from 1 to 2.5 cm thick. This often results in tank punctures and ruptures leading to fires and explosions in severe accidents. A used fuel package certified to Type B safety standards is designed to withstand severe transport accidents. Demonstration tests (Section 4) and analyses based on accident reconstructions (Section 5) have consistently shown that certified UNF package designs can resist the most severe real-world accidents, including severe accidents involving the derailment of trains carrying flammable dangerous goods.

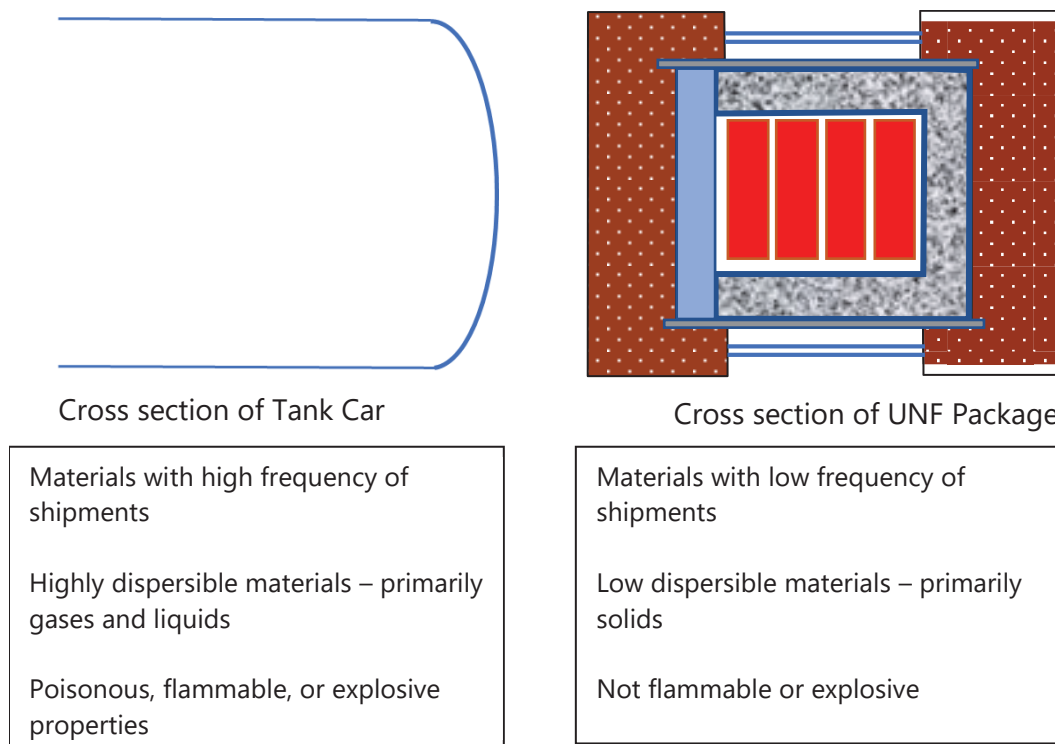


Figure H-3: Comparison of shipment made in tank cars versus UNF shipments

In contrast, a UNF package contains a solid low dispersible material that will not explode or cause a fire and has a low frequency of shipments. UNF packages designed to meet Type B package standards result in thick-walled packages (see Section 3.2.1.3) that contain no exposed openings and lids that are welded or bolted shut.

APPENDIX I RELEASE PATHWAYS FOR RADIOACTIVE MATERIAL IN SEVERE TRANSPORTATION ACCIDENTS

There are two main barriers to the release of radioactive material from used fuel packages during a severe transportation accident. The first barrier is the design of the transportation package itself. Used fuel is transported in a Type B package that is designed to withstand severe accidents without a significant loss of containment or an increase in external radiation that would endanger first responders or the general public. In meeting the Type B design standards, the package designer must demonstrate that a package can prevent puncture and protect the lid or welded closure from being significantly damaged or displaced, thus showing that radioactive material is being adequately contained.

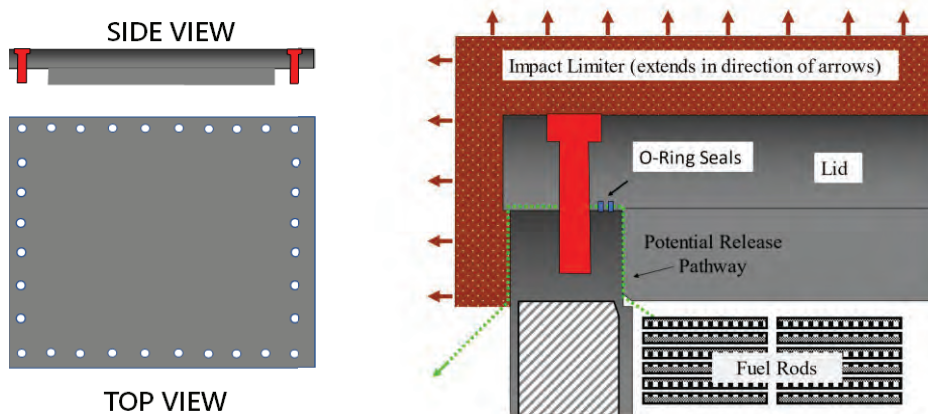
The second barrier is the fuel rod cladding or sheathing. The sheathing for most commercial nuclear fuel is made from zirconium metal alloy, which is fabricated into metal tubes. These tubes contain uranium dioxide pellets. The tubes are pressurized to resist collapse or leaks when used in the high-pressure operating environment of a nuclear reactor core. Fuel rods are grouped together in bundles using metal structural supports. These supports help prevent fuel rods from buckling in a severe transportation accident. The intact sheathing provides a containment barrier that prevents used nuclear fuel particles from escaping from within the tubes to the inside of the package. CANDU fuel sheath failure may occur if the internal gas pressure inside a fuel tube causes the sheathing to strain. The sheathing for CANDU fuel approaches the onset of ballooning (a precursor to sheath failure due to overstrain) once its temperature surpasses approximately 650°C [101].

The release of a significant quantity of radioactive material from a loaded Type B used fuel transport package during a severe accident would occur only if the package and one or more fuel rods were breached. A breach in a fuel rod could occur from either mechanical or thermal rupture.

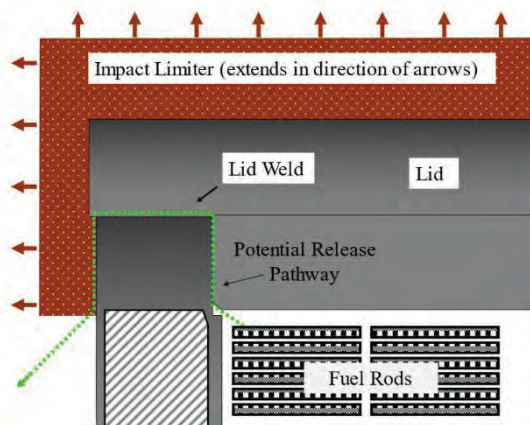
Figure I-1 illustrates the pathways from which radioactive material could be released from a UNF package having both bolted and welded lids. The potential release path for a package with a bolted lid leads from inside the package through the tight clearance between lid and the inner wall of package, passes by double O-ring seals, then through the clearance between lid and package's lid sealing surface. The clearance between the lid and the lid sealing surface is very narrow, plugs easily, and prohibits all but the tiniest particles from passing. The clearance is very narrow because the lid is clamped down by a large number of highly torqued (tightened) bolts.

The package will only leak when the lid is somehow dislodged or distorted, and the fuel sheathing is breached.

The potential release path for a package with a welded lid leads from inside the package through the tight clearance between lid and the inner wall of package, then through a crack in the weld. The package will only leak when the lid weld is cracked, and the fuel sheathing is breached.



Release Pathway for Bolted Lid



Release Pathway for Welded Lid

Figure I-1: Pathways for release of radioactive material

APPENDIX J MISSISSAUGA TRAIN DERAILMENT

J.1 THE ACCIDENT

The Mississauga train derailment was a railway accident that occurred a few minutes before midnight on November 10, 1979, in Mississauga, Ontario, Canada. The accident involved a Canadian Pacific Railway (CPR) freight train carrying a variety of dangerous goods, including propane, toluene, styrene, and chlorine. At the point of derailment, the train was traveling about 80 km/h. In total, 24 cars derailed. Fire spread through most of the derailed cars, and three tank cars that were loaded with propane exploded causing considerable property damage. A tank car carrying chlorine suffered a 76 cm (2½ foot) diameter hole, and because of concern of the health effects of escaping chlorine, approximately 218 000 people were evacuated from the city of Mississauga and its surrounding areas for periods of up to five days. Fortunately, there were no fatalities resulting from the accident, but over 200 people were injured, mostly due to exposure to toxic chemicals. The cause of the accident was determined to be a broken rail, which caused the train to derail.

J.2 THE TRAIN AND ITS CARGO

At the time of the derailment, the freight train consisted of 3 engines and 106 cars. Eighty-four cars were loaded (38 with dangerous goods) and 22 were empty. Twenty-four of the 106 cars derailed. These cars were in the 33rd through 56th positions in the train. Figure J-1, taken from the Grange Accident Inquiry [90], shows the contents and final positions of the 24 derailed cars. In Figure J-1, the derailed cars are numbered from 1 through 24. The derailed train cars were carrying the following dangerous goods:

- Cars 1,16 and 24 : Toluene – colorless flammable liquid (boiling point: 110 °C) shipped in 18 400-gal (69 651 L) DOT 111 tank cars.
- Cars 3,4,5 and 6 : Caustic Soda - sodium hydroxide solution (boiling point: > 142 °C) shipped in 18 400-gal (69 651 L) DOT 111 tank cars.
- Car 7 : Chlorine – toxic gas (boiling point: -34 °C) shipped in 17 360-gallon (65 715 L) DOT-105 tank cars.
- Cars 8,12,13,14, 17-23: Propane – flammable liquid (boiling point: -42 °C) shipped in DOT-117 tank cars.
- Cars 9, 10 and 11 : Styrene monomer – clear pale yellow oily liquid (boiling point: 145 °C) shipped in 26 000-gallon (98 421 L) DOT-111 tank cars.

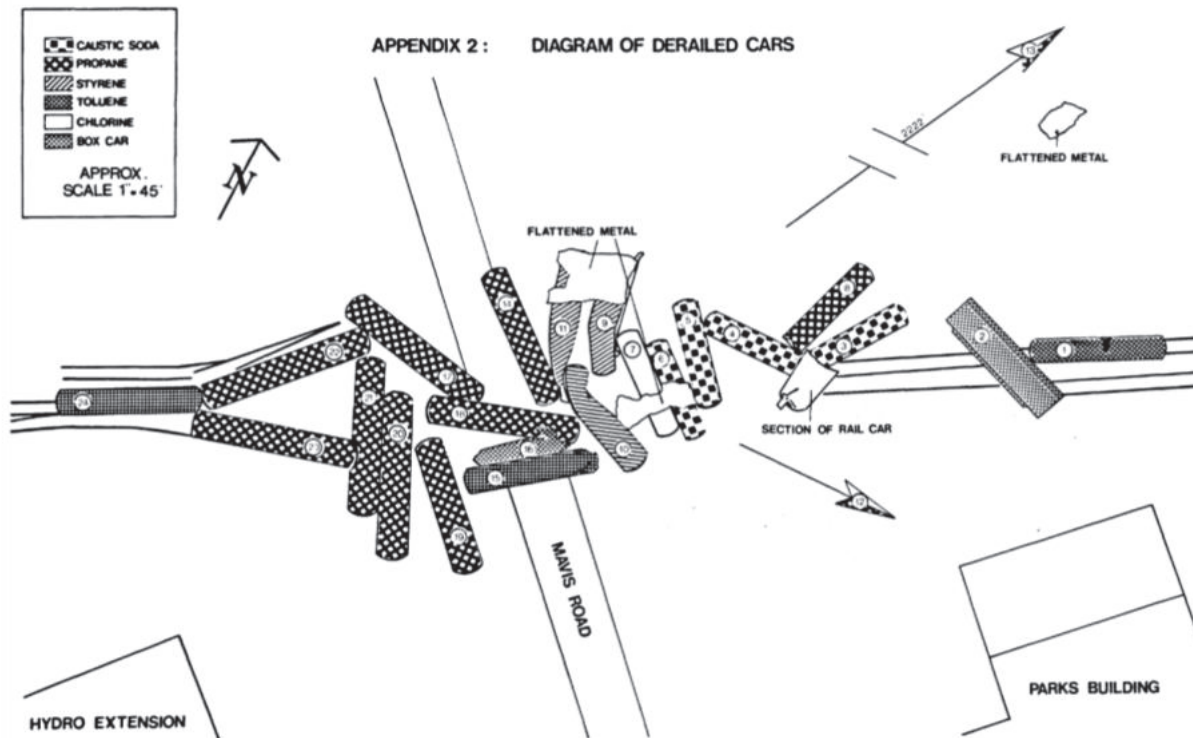


Figure J-1: Derailment diagram from Accident Inquiry [90]

J.3 THE TIMELINE AND CONSEQUENCES

The derailment occurred at approximately 11:56 p.m. on November 10, 1979. An explosion and fireball occurred shortly thereafter. This explosion and fireball were the result of a propane tank car (car 8) undergoing a boiling liquid expanding vapour explosion (BLEVE)²¹.

A second explosion was reported at 1:09 a.m. (November 11), followed by a third explosion at 1:16 a.m. Both of these explosions were attributed to propane tank cars (Cars 12 and 13) undergoing BLEVEs. During a BLEVE, a tank car will fragment into pieces forming projectiles that travel at high speed and can be thrown large distances (~1 km). Shock waves from a BLEVE can lead to damaging overpressures resulting in structural damage to buildings, etc. Simultaneously, the liquid/vapors are ignited to form a spherical partially pre-mixed flame termed a fireball. As much as one third of contents of a propane tank car can be consumed in a fireball. A typical fireball from a railcar carrying hydrocarbons will last from 10 to 30 seconds and can have a diameter of 200 to 300 meters [102]. Figure J-2 illustrates a fireball from the Mississauga derailment.

²¹ BLEVE - an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure. BLEVEs can be caused by structural damage to a tank car, or by pool fire impinging on a tank car increasing its temperature and pressure causing the tank to rupture.



Figure J-2: Mississauga derailment - Left: Fireball, Right: Propane tank car fires

After the initial fireball, a fire from a propane tank car will generally be confined to or near the point of release from the tank car. Propane will generally not form liquid pools because it vaporizes rapidly at or above room temperature.

The police were the first to respond arriving shortly after midnight. The fire department responded within eight minutes of the derailment (12:04 a.m.) and deployed fire fighting equipment. In fighting a propane fire, it is not always necessary to extinguish the fire. The main objective is to cool the tank car to avert a BLEVE. In fact, if a propane tank car fire is extinguished without being able to seal the leak, a subsequent explosion could result. In most accidents involving propane tank cars, the remaining propane in a tank car is subsequently flared off as it represents the safest way to remove it. Figure J-3 depicts a flaring operation that was undertaken during the aftermath of a propane train derailment in Weyauwega, Wisconsin (March 8-16, 1996). This flaring operation can result in a precautionary evaluation of surrounding areas and often results in accidents being reported with a long duration when the immediate danger is long past.



Figure J-3: Tank flaring in Weyauwega, Wisconsin

At 2:35 a.m., the fire was reported to be contained. The contained fire for the Mississauga derailment is shown in Figure J-4. Note that the fires are located at the points of release from the tank cars and that none of the railcars are "fully engulfed" by fire. Beyond this point, there were no explosions or periods where the fire was not firmly under control.



Figure J-4: Fire containment in the Mississauga derailment

After the fire was contained, the focus of the accident response was on preventing the further release of chlorine and moving people beyond harm's way. As stated in the Accident Inquiry report:

"The main problem, however, was not with the propane explosions however spectacular and potentially dangerous they may have been. What most concerned the authorities was that it was apparent almost from the beginning that some Chlorine was escaping into the air and it became known at least by the early morning of Monday, November 12, that Car 7 in the derailment, the Chlorine car, had a hole between 2 and 3 feet in diameter. No one could make an exact measurement of the amount of Chlorine remaining in the car and no one could give a guarantee that what remained would not be released in either the process of sealing the hole or in the process of removing the Chlorine from the sealed tank. As a result, a large portion of Mississauga together with a small part of Oakville to the west and isolated pockets of Etobicoke, a Borough of Metropolitan Toronto to the east, was evacuated on Sunday, November 11, and the area of Mississauga from Burnhamthorpe Road south to Lake Ontario, and from Highway 10 on the east to Erin Mills Parkway and Southdown Road on the west—an area of about 45 square kilometers (17.4 square miles) involving close to 75 thousand people remained evacuated until Friday, November 16. Even then, however, the Chlorine car was not completely empty. The draining of Chlorine and the clean-up of the site continued for some days, once again fortunately without casualty."

J.4 POTENTIAL IMPACT ON A USED NUCLEAR FUEL PACKAGE

Several aspects must be considered when evaluating the performance of a used fuel package, such as the Dry Storage Container Transportation Package (DSC-TP), had it been in an accident such as the Mississauga train derailment. These include the potential damage to the package body or welded closure area from direct impact, puncture, explosions and long duration severe fires. The release of radioactive material will only occur if the DSC-TP side wall is breached or the lid (welded closure area) is severely damaged.

J.4.1 Direct Impact

The train was traveling approximately 80 km/h when it derailed. This speed represents an upper bound on impact speed. The impact to a DSC-TP would result from the DSC-TP colliding with an adjacent railcar, most likely in a side to side impact. This results from the tendency of railcars to end up in accordion-like patterns in derailments.



Figure J-5: Tank railcar (left) and used fuel railcar (right) – note that the DSC-TP is shipped horizontally

In addition, some of the impact force would be absorbed by the used fuel package transport railcar. Unlike tank railcars, used fuel packages are attached to the railcars using tie-downs. (Figure J-5). The SANDIA tests, described in Section 4.2, are an example of the ability of used fuel package railcars to absorb the forces of direct impact. The impact limiters for the DSC-TP also provide protection to the lid area during impact, and the side protection shield provides additional resistance to a side impact. The body of the DSC-TP is approximately 54.9 cm thick (i.e., a 52.3 cm concrete shell encased in two 1.27 cm carbon steel shells). The lid is sealed using multiple weld passes.

The impact forces experienced by the DSC-TP during the Mississauga train derailment would be several orders of magnitude lower than the forces measured in the 160 km/h train collision described in Operation Smash Hit (described in Section 4.3). Operation Smash Hit simulated a rail accident that consisted of a 140 metric ton locomotive traveling at 160 km/h colliding directly with a stationary 47 metric ton Magnox flask attached to a 13 metric ton railcar. The flask and railcar were oriented so that the locomotive would strike directly on the package lid edge at the most vulnerable orientation. The orientation of the flask was chosen to represent the most vulnerable location, near the lid seal region which consisted of a bolted lid and O-rings. The full-scale simulation demonstrated that the Magnox package could survive a severe rail accident

with surficial surface damage, minimal damage to the lid seal region, and no significant release of radioactive materials.

In comparison, the DSC-TP is a heavier package (100 metric tons when loaded), and has a welded lid. The impact speeds and forces during the Mississauga derailment (which derailed at 80 km/h) are much smaller than the forces involved in a direct collision of a locomotive traveling at 160 km/h (such as Operation Smash Hit). The impact forces on the DSC-TP that would have occurred during the Mississauga train derailment would be not be sufficient to either breach the package wall or severely damage the package's welded closure area.

J.4.2 Puncture

The DSC-TP has thick walls that are made of carbon steel encased concrete. The total wall thickness consists of a 52.3 cm (20.6 in) thick layer of concrete encased by two 1.27 cm (0.5 inch) thick carbon steel shells. The 52.1 cm (20.5 in) thick package lid consists of concrete encased in a carbon steel shell. The top and bottom of the package are protected by polyurethane foam impact limiters encased in stainless steel shells. The DSC-TP uses double layered side protection during transportation. The side protection consists of two layers – an inner stainless steel shell that is 1.3 cm (0.5 in) thick and an outer stainless steel shell that is 0.95 cm (0.375 in) thick. The shells extend downward from the top impact limiter and upward from the bottom impact limiter and overlap around the circumference of the DSC-TP.

Data from the U.S. Nuclear Regulatory Commission (NRC) and Association of American Railroads (AAR) (presented in Section 3.2.1.3) show that rail tank cars with thicknesses greater than one inch (2.54 cm) are highly unlikely to be punctured in severe rail accidents. Contrasting the AAR data to the wall and lid thicknesses of UNF packages, it is not expected that a breach of the package wall or severe damage to the package's welded closure area would take place in a derailment scenario, such as the Mississauga accident. Design features of the DSC-TP are shown in Section 3.4 of the report.

J.4.3 Explosion

The Mississauga train derailment resulted in the BLEVE of three propane tank cars. The impact damage from a BLEVE results from the shock waves created and the fragments of the exploding tank car that may be projected with great force and over long distances. Because the occurrence of BLEVEs is not uncommon in severe transportation accidents, the ability of used fuel packages to withstand the effect of a BLEVE has been studied by multiple research and regulatory bodies.

One study of particular relevance to the Mississauga train derailment is the physical demonstration test of a propane tank car BLEVE next to a CASTOR THTR/AVR used fuel package conducted by the German Federal Institute for Materials Research and Testing (BAM) [103]. The demonstration test is described in more detail in Section 4.4.1.

During the test, the propane tank BLEVE resulted in a severe impact of rail tank car fragments with the CASTOR package and caused the 22 450 kg package to be flipped over, landing 7-10 meters from its original location. The BLEVE caused only superficial damage (deep scratches and imprints from the impacting railcar fragments) to the package body and did not significantly affect the integrity of the package's bolted lids. The integrity of the package's lids was confirmed as the measured leak rate from the lid seals was the same before and after the test. The impact on the package was determined to be on the same order of magnitude from the regulatory drop test (9 meters onto an unyielding surface).

In comparison, the DSC-TP is a heavier package (100 metric tons when loaded) and has a welded lid. The impact forces from a BLEVE during the Mississauga derailment would be similar to those experienced in the BAM test since they both involved exploding propane tanks. The impact forces on the DSC-TP that would have occurred during from a BLEVE in the Mississauga train derailment would not be sufficient to either breach the package wall or severely damage the package's welded closure area.

J.4.4 Fire

The fires that occurred during the Mississauga derailment involved the burning of propane, toluene and styrene monomers. These fires burn at an average of approximately 800°C. In addition, the fire only lasted about 2 ½ hours before it was fully contained.

The impact of the fire on the DSC-TP would depend on the package's location in the fire. As a condition of approval, the DSC-TP was evaluated in a fully engulfing fire – this means that 100% of the package surface is exposed to the fire's heat flux. From the accident diagram (Figure J-1) and photos (Figure J-4) of the Mississauga train derailment, it is evident that one or more sides of the DSC-TP would likely be protected by the transport vehicle involved in the accident, or the fire would be only on one side of the package. The package would also rest on the ground which would reduce the surface area exposed in an accident as compared to the fully engulfing fire required in the regulations. In addition, the lid area is covered by impact limiters that act as insulators or heat shields.

Given the large thermal inertia of the 100 metric ton DSC-TP, the relatively short duration of the fire (2 ½ hours) and the fact that the fire would not be fully engulfing, the package would be unlikely to experience temperatures that would adversely affect the integrity of the package body or lid seal region.

J.4.5 Summary

None of the forces (impact, puncture, or explosion), or the fire that occurred in the Mississauga train derailment would be sufficient to either breach the DSC-TP package wall or severely damage the package's welded closure area.

APPENDIX K HINTON TRAIN COLLISION

K.1 THE ACCIDENT

The Hinton train collision was a railway accident that occurred on February 8, 1986, near the town of Hinton, Alberta, Canada. The accident involved a westbound freight train and an eastbound passenger train, which collided head-on on a single-track section of the Canadian National Railway (CN) mainline. The passenger train was the Via Rail Canadian, enroute from Vancouver to Toronto, traveling at 79 km/h and was carrying 170 passengers and 2 crew. The freight train consisted of three locomotives and 114 loaded cars traveling at 95 km/h carrying a crew of three. The collision resulted in the deaths of 23 people, including two crew members on the freight train, and 19 passengers and two crew members on the passenger train. The freight train derailed. The cause of the accident was determined to be a breakdown in communication between the two trains and a failure of the automatic block signal system. After the crash, diesel fuel spilled from the locomotives and ignited, engulfing the locomotives, the baggage car, and the day coach.



Figure K-1: Hinton train collision – freight train (left) and passenger train (right)

Eighteen of the 36 occupants on the day coach were killed. The contents of a grain car were propelled on top of the day coach, helping to smother the fire. The observation dome car behind the day coach suffered serious damage and was also hit by a freight car. One of its occupants was killed. The others were able to escape either through a broken window in the dome or through the hole left by the freight car. The two sleepers following the dome car derailed and were thrown on their sides. There were no deaths in these cars, but there were several injuries. The three passenger cars at the rear of the train did not derail, but there were some injuries.

As the accident unfolded, the cars on the freight train piled up on each other, resulting in a large pile of rolling stock. The three freight locomotives and the first 76 cars of the freight train were either destroyed or damaged.

K.2 THE TRAINS AND THEIR CARGO

The freight train consisted of three locomotives, 114 loaded freight cars and a caboose as described in Table K-1. None of the railcars carrying dangerous goods derailed or released contents.

Table K-1: Composition of freight train

Freight Train Consist			
Position	Type of Car	Contents	Accident Status
1-3	Locomotives	2 crew	Derailed
4	Highspeed spreader	-	Derailed
5-39	Hopper cars	Grain	Derailed
40-46	Flat cars	78 Inch Diameter Pipe	Derailed
47-91	Open top hopper cars	Sulphur	33 Derailed
92-103	Tank cars	Caustic Soda	Did Not Derail
104-111	Tank cars	Ethylene Dichloride	Did Not Derail
112-117	Hopper cars	Grain	Did Not Derail
118	Caboose	1 crew	Did Not Derail

The composition of the passenger train is given in Table K-2. Ten cars from the passenger train derailed, including a day coach and dome car. The fatalities that occurred were in the first five cars.

Table K-2: Composition of passenger train

Passenger Train Consist			
Position	Type of Car	Fatalities	Accident Status
1-2	Locomotives	2 Fatalities (crew)	Derailed
3	Baggage Car	-	Derailed
4	Day Couch/ Lounge	18 Fatalities	Derailed
5	Dome Car/ Lounge	1 Fatality	Derailed
6	Sleeper	-	Derailed
7	Sleeper	-	Derailed
8	Locomotive	-	Derailed
9	Steam Generator Car	-	Derailed
10	Baggage Car	-	Derailed
11	Day-Nighter Coach	-	Did Not Derail
12	Café/Lounge Car	-	Did Not Derail
13	Sleeper	-	Did Not Derail
14	Steam Generator Car	-	Did Not Derail

K.3 POTENTIAL IMPACT ON A USED FUEL PACKAGE

Several aspects must be considered in order to evaluate the performance of a used fuel package, such as the Dry Storage Container Transportation Package (DSC-TP), in accidents such as the Hinton train collision. These include the potential damage to the package body or welded closure area from (1) direct impact, (2) puncture, (3) explosions and (4) long duration severe fires. The release of radioactive material will only occur if the DSC-TP body wall is breached, or the welded closure area is severely damaged.

K.3.1 Direct Impact

The passenger train (travelling at 79 km/h) and freight train (travelling at 95 km/h) collided at a combined speed of approximately 184 km/h. This speed represents an upper bound on impact speed. The combined impact speed of 184 km/h would only be experienced by the locomotives at the front end of the two trains. The cars that derailed on the freight train derailed at a much lower speed (< 95 km/h). In general, the speed of collision and impact forces of a railcar decrease with the distance of the railcar from the front or back of a train (i.e., point of collision).

The impact to a DSC-TP in a derailment would result from the DSC-TP colliding with an adjacent railcar, most likely in side-to-side impacts. This results from the tendency of railcars to end up in accordion like patterns in derailments. This accordion like pattern can be seen in Figure K-1 (left).

In addition, some of the impact force would be absorbed by the used fuel package transport railcar. Unlike rail tank cars, used fuel packages are attached to the railcars using tie-downs (Figure K-2). The SANDIA tests, described in Section 4.2, are an example of the ability of used fuel package railcars to absorb the forces of direct impact. The impact limiters for the DSC-TP also provide protection to the lid area during impact, and the side protection shield provides additional resistance to a side impact.



Figure K-2: Tank railcar (left) and used fuel railcar (right) – note that the DSC-TP is shipped horizontally

The impact forces experienced by the DSC-TP during the Hinton train collision and derailment would be significantly lower than the forces measured in the 160 km/h train collision described in Operation Smash Hit (described in Section 4.3). Operation Smash Hit simulated a rail accident that consisted of a 140 metric ton locomotive traveling at 160 km/h colliding directly with a stationary 47 metric ton Magnox flask attached to a 13 metric ton railcar. The flask and railcar were oriented so that the locomotive would strike directly on the package lid edge at the most vulnerable

orientation. The orientation of the flask was chosen to represent the most vulnerable location, near the lid seal region which consisted of a bolted lid and O-rings. The full-scale simulation demonstrated that the Magnox package could survive a severe rail accident with superficial surface damage, minimal damage to the lid seal region, and no significant release of radioactive material.

In comparison, the DSC-TP is a heavier package (100 metric tons when loaded), and has a welded lid. The impact speeds and forces during the Hinton derailment (which derailed at 95 km/h) are much smaller than the forces involved in a direct collision of a locomotive traveling at 160 km/h (such as Operation Smash Hit). The impact forces on the DSC-TP that would have occurred during the Hinton train derailment would be not be sufficient to either breach the package wall or severely damage the package's welded closure area.

K.3.2 Puncture

The DSC-TP has thick walls that are made of carbon steel encased concrete. The total wall thickness consists of a 52.3 cm (20.6 in) thick layer of concrete encased by two 1.27 cm (0.5 inch) thick carbon steel shells. The 52.1 cm (20.5 in) thick package lid consists of concrete encased in a carbon steel shell. The top and bottom of the package are protected by polyurethane foam impact limiters encased in stainless steel shells. The DSC-TP uses double layered side protection during transportation. The side protection consists of two layers – an inner stainless steel shell that is 1.3 cm (0.5 in) thick and an outer stainless steel shell that is 0.95 cm (0.375 in) thick. The shells extend downward from the top impact limiter and upward from the bottom impact limiter and overlap around the circumference of the DSC-TP.

Data from the U.S. Nuclear Regulatory Commission (NRC) and Association of American Railroads (AAR) (presented in Section 3.2.1.3) show that rail tank cars with thicknesses greater than one inch (2.54 cm) are unlikely to be punctured in severe rail accidents. Contrasting the AAR data to the wall and lid thicknesses of UNF packages, it is not expected that a breach of the package wall or severe damage to the package's welded closure area would take place in a derailment scenario such as the Hinton train collision and derailment. Design features of the DSC-TP are shown in Section 3.4 of the report.

K.3.3 Explosion

No explosions occurred in the Hinton rail collision. The only dangerous good on the freight train that could be involved in an explosion was ethylene dichloride – a flammable liquid. There are two types of explosions possible. The first is a boiling liquid expanding vapour explosion (BLEVE)²²

²² BLEVE - an explosion resulting from the failure of a vessel containing a liquid at a temperature significantly above its boiling point at normal atmospheric pressure. BLEVEs can be caused by structural damage to a tank car, or by pool fire impinging on a tank car increasing its temperature and pressure causing the tank to rupture.

resulting from the sudden vaporization of a liquid. The second type is a vapor cloud detonation (VCD) caused by the ignition of a flammable vapor cloud.

Ethylene dichloride has a boiling point of 83.5°C. Because the boiling point of ethylene dichloride is significantly higher than ambient temperature, a tank car carrying ethylene dichloride cannot undergo a BLEVE.

A VCD will only occur when the following five conditions are met: fuel, oxidizer, ignition source, dispersion and confinement. It is the lack of dispersion and confinement that keeps most flammable materials from exploding in VCDs. Therefore, the most likely result from the rupture of a tank car containing ethylene dichloride is a leak and subsequent fire.

If a VCD would have occurred, the impacts would likely be bounded by the physical demonstration test conducted by the German Federal Institute for Materials Research and Testing (BAM) of a propane tank car BLEVE next to a CASTOR THTR/AVR used fuel package [103]. The demonstration test is described in more detail in Section 4.4.1.

During the test, the propane tank BLEVE resulted in a severe impact of rail tank car fragments with the CASTOR package and caused the 22 450 kg package to be flipped over landing 7-10 meters from its original location. The BLEVE caused only superficial damage (deep scratches and imprints from the impacting railcar fragments) to the package body and did not significantly affect the integrity of the package's bolted lids. The integrity of the package's lids was confirmed as the measured leak rates from the lid seals was the same before and after the test. The impact on the package was determined to be on the same order of magnitude from the regulatory drop test (nine meters onto an unyielding surface).

In comparison, the DSC-TP is a heavier package (100 metric tons when loaded) and has a welded lid. The impact forces from a VCD during the Hinton train collision would be bounded by those experienced in the BAM test. The major difference between a BLEVE and VCD is that VCD does not involve the fragmentation and projection of tank fragments from the tank car. The shockwaves are similar. Based on the BAM test, it is likely that the explosive impact forces on the DSC-TP that would have occurred from a VCD in the Hinton train derailment would not be sufficient to either breach the package wall or severely damage the package's welded closure area.

K.3.4 Fire

The fire that occurred during the Hinton collision and derailment involved the burning of diesel oil fuel leaking from the locomotives. Diesel oil fires burn at an average of approximately 800°C. Figure K-1 (left) and Figure K-3 show the localized nature of the fire. As such, the fire would not have impacted a used fuel package carried on the train.

If the fire had been more widespread²³, the impact of the fire on the DSC-TP would be determined by its location in the fire. As a condition of approval, the DSC-TP was evaluated in a fully engulfing fire – this means that 100% of the package surface is exposed to the fire’s heat flux. From the accident photo in Figure K-1 (left) of the Hinton train collision, it is evident that the railcars ended up in accordion like patterns. This would likely result in one or more sides of the DSC-TP being shielded from the fire by an adjacent railcar. The DSC-TP would be shielded by the transport vehicle on which it is being transported. The package would also rest on the ground which would reduce the surface area exposed in an accident as compared to the fully engulfing fire required in the regulations. In addition, the lid area is covered by impact limiters that act as insulators or heat shields.



Figure K-3: Hinton collision showing the aftermath of a fire involving locomotives diesel fuel

Given the large thermal inertia of the 100 metric ton DSC-TP, and the fact that the fire would not be fully engulfing, the package is unlikely to experience temperatures that would adversely affect the integrity of the package body or lid seal region.

K.3.5 Summary

Neither the impact or puncture force that occurred in the Hinton train collision and derailment would be sufficient to either breach the package wall or severely damage the package’s welded closure area. The Hinton collision resulted in a very localized diesel fire that would not have seriously impacted a used fuel package. There were no explosions. No release of radioactive

²³ The freight train was carrying eight tank cars of ethylene dichloride – a flammable liquid.

material or increase in external radiation would have occurred under the conditions actually experienced in the Hinton collision.

It is also highly unlikely that a release of radioactive material or increase in external radiation would have occurred had the collision resulted in a larger fire or vapor explosion from damage to one or more of the eight tanks cars of ethylene dichloride.

APPENDIX L JAMES SNOW PARKWAY

L.1 THE ACCIDENT

The James Snow accident occurred on March 24, 1986, when a gasoline tanker truck on Highway 401 near Milton, Ontario, collided with a flatbed truck. The gasoline tanker which was carrying 51 000 liters of gasoline rolled onto its side and slid down the highway to the James Snow Parkway overpass. The tanker then exploded and erupted into a fireball [104]. The Calgary Herald reported that the resulting fire caused concrete to burn away, exposing the inner steel reinforcing cables of the overpass²⁴ [104]. The tanker truck was reported to be an upside-down unrecognizable skeleton of a truck. The Ottawa Citizen reported that the intense heat from the fire melted the reinforcing rods in the concrete bridge [105].

L.2 POTENTIAL IMPACT ON A USED FUEL PACKAGE

Several aspects must be considered to evaluate the performance of a used fuel package, such as the UFTP, in accidents such as the James Snow Parkway collision. These include the potential damage to the package body or lid sealing area²⁵ from (1) direct impact, (2) puncture, (3) explosions and (4) long duration severe fires. The release of radioactive material will only occur if the package wall is breached, or the lid (sealing area) is severely damaged.

L.2.1 Direct Impact

The impact forces experienced by a UNF package during a tanker truck collision would be significantly lower than the forces measured in the 160 km/h train collision described in Operation Smash Hit (described in Section 4.3). Operation Smash Hit simulated a rail accident that consisted of a 140 metric ton locomotive traveling at 160 km/h colliding directly with a stationary 47 metric ton Magnox flask attached to a 13 metric ton railcar. The flask and railcar were oriented so that the locomotive would strike directly on the package lid edge at the most vulnerable orientation. The orientation of the flask was chosen to represent the most vulnerable location, near the lid seal region which consisted of a bolted lid and O-rings. The full-scale simulation demonstrated that the Magnox package could survive a severe rail accident with superficial surface damage, minimal damage to the lid seal region, and no significant release of radioactive materials.

²⁴ The reinforcing cables are steel cables and bars (rebars) used to reinforce concrete structures in the overpass. They are embedded in the concrete.

²⁵ The lid sealing area includes the lid, O-ring seals, and lid mating surface.

L.2.2 Puncture

The UFTP is a UNF package designed primarily for road transport. It has nearly 30 cm (11 inch) thick stainless steel walls and lid. During transport, the top of the UFTP is protected by an impact limiter consisting of a redwood core enclosed within a stainless steel shell.

Data from the U.S. Nuclear Regulatory Commission (NRC) and Association of American Railroads (AAR) (presented in Section 3.2.1.3) show that rail tank cars with thicknesses greater than one inch are unlikely to be punctured in severe rail accidents. Contrasting the AAR data to wall and lid thicknesses of UNF packages, it is not expected that a breach of the package wall or severe damage to the package's sealing area would take place in a derailment scenario such as the James Snow Parkway accident. Design features of the UFTP are shown in Section 3.4 of the report.

L.2.3 Fire

The James Snow accident involved a fire that occurred in a "partially enclosed" space. Fires occurring in enclosed spaces generally involve higher temperatures, and are more engulfing than pool fires that occur in the open [106], [107], [108], [109], [110]. In an open pool fire, a significant amount of heat is transferred to the environment by the buoyancy of the flames. As the heated combustion products rise, the fire draws in fresh cooler air creating a turbulent air flow. This process is referred to as air entrainment. For hydrocarbon fuels, the turbulent flame temperature is independent of the fuel and can be approximated by 800°C [111]. In contrast, in an enclosed or partially enclosed fire, much of the heat from the rising hot gases is transferred to the surface of the enclosure where it is reradiated back to the package surface. This results in higher flame temperatures in enclosed spaces than those that are characteristic of open pool fires.

Table L-1 shows several highway accidents that have been evaluated to determine what impact a fire occurring in an enclosed space might have on a used fuel package. The temperatures generally range about 200 to 300 degrees centigrade higher than the 800°C found in open pool fires. In the first two accidents, the fire was caused by a ruptured gasoline tanker. The third accident involved multiple trucks carrying common goods, mostly food stocks. The fire durations were determined from accident reports. The MacArthur Maze accident was modeled as a two part fire: a 37 minute fire at 1040°C followed by a 71 minute fire at 900°C.

Table L-1: Accidents involving fires in enclosed spaces

Accident	Type	Fuel Source	Used Fuel Package	Maximum Fire Temp.	Fire Duration
Caldecott Tunnel [112]	Enclosed highway tunnel	33 310 liters gasoline	NAC-LWT	1040°C	40 min
MacArthur Maze [113]	Highway underpass	32 554 liters gasoline	GA-4	1100°C 900°C	37 min 71 min
Newhall Pass [114]	Highway underpass	Common Goods	GA-4	1088°C	33 min

The James Snow accident involved an overturned tanker truck carrying approximately 51 000 liters of gasoline. Thus, it would be possible that the flame temperature in an accident similar to the James Snow accident could exceed the fire test temperature of 800°C, and could be as high as 900-1100°C (similar to the MacArthur Maze fire described above).

As described in Appendix I, there are two main barriers that prevent the release of radioactive material in severe accidents: the package lid seals and the used fuel sheathing. Both must fail to result in the release of radioactive material from the package. When the lid is bolted, the seal comes from two O-rings that are compressed between the lid and package body by the clamping forces of highly torqued bolts. Thus, in a severe fire the operating temperature of the O-rings becomes important. If the operating temperature is exceeded, the lid seals are assumed to have lost the ability to provide a seal. Even if the lid seals are assumed to have failed, the clearance between the lid and package body remains tight and prevents the release of all but the very smallest particles.

Table L-2 shows the characteristics of the packages used in the fire studies previously described and the UFTP envisioned for use in the NWMO's transportation program. The UFTP is heavier than the GA-4 and NAC-LWT packages. This implies that it has a similar or greater thermal inertia; i.e., it can absorb a similar or greater amount of heat per change in temperature.

Table L-2: Characteristics of used fuel packages used in accident evaluations

Accident	Package	Package Weight, kg	Package Contents	Lid Closure	Shielding	Package Walls
Caldecott Tunnel [112]	NAC-LWT	23 586	1 PWR	Bolted	Lead	Stainless steel
MacArthur Maze [113]	GA-4	24 948	4 PWR	Bolted	DU	Stainless steel
Newhall Pass [114]	GA-4	24 948	4 PWR	Bolted	DU	Stainless steel
James Snow	UFTP	34 800	192 Bundles CANDU	Bolted	Monolithic stainless steel	

Table L-3 shows the lid seal temperatures calculated for the Caldecott Tunnel, MacArthur Maze and Newhall Pass fires. In all cases, the temperatures exceeded the operating temperatures for the lid, drain and vent ports seals. The drain and vent ports are small openings that allow packages to be drained and gas samples to be taken. The drain and vent ports are recessed and are covered by bolted lid plates sealed with O-rings. This can create a release pathway to the interior of the package. However, as previously stated, the clearance between the lid and package body is very small and would prevent the release of all but the very smallest particles. However, the analyses for the three accidents show that enclosed fires can produce temperatures hot enough to affect the performance of Type B package seals in a severe fire – especially those seals made of polymeric elastomers.

Table L-3: Lid seal temperatures for UNF packages in severe fires

Accident	Package	Max Fire Temp. (duration)	Max Lid Seal Temp	Lid Seal Operating Limit	Maximum Vent and Drain Port Seal Temp	Vent and Drain Port Seal Operating Limit
Caldecott Tunnel [112]	NAC-LWT	1040°C (40 min)	424°C	391°C (TFE) 288°C (Viton)	698°C	391°C (TFE) 288°C (Viton)
	NAC-LWT (within ISO Container)	1040°C (40 min)	393°C	391°C (TFE) 288°C (Viton)	557°C	391°C (TFE) 288°C (Viton)
MacArthur Maze [113]	GA-4	1100°C (37 min) 900°C (71 min)	621°C	421°C (ethylene propylene)	621°C	421°C (ethylene propylene)
Newhall Pass [114]	GA-4	1088°C (33 min)	560°C	421°C (ethylene propylene)	513°C (Vent) 520°C (Drain)	421°C (ethylene propylene)

The three accident scenarios were evaluated to determine the possible effects of enclosed fires on the performance of the used fuel transported. Table L-4 shows the maximum sheathing temperatures calculated for the Caldecott Tunnel, MacArthur Maze, and Newhall Pass fires. The maximum temperature calculated (MacArthur Maze: 753°C) exceeded the theoretical rupture limit for light water reactor fuel that it was certified to transport.²⁶ The maximum sheathing temperature for the Newhall Pass fire was 534°C which was within 30 degrees of the theoretical rupture limit for light water reactor fuel that it was certified to transport. The sheathing rupture temperature was not exceeded in the Caldecott accident scenario. Different used fuels have different rupture temperatures based on their different properties, such as burnup (i.e., time in a reactor) and aging (i.e. cooling time once the fuel is removed from a reactor). The analyses for the three accidents show that enclosed fires can produce temperatures hot enough to affect the performance of sheathing in a severe fire.

²⁶ The theoretical sheathing rupture temperatures used are temperatures at which the sheathing the onset of localized instability. This is the point that sheathing may experience rapid ballooning leading to failure.

Table L-4: Sheathing rupture temperatures for UNF packages in severe fires

Accident	Package	Maximum Temperature (Fire duration)	Maximum Sheathing Temperature	Sheathing Rupture Temperature
Caldecott Tunnel [112]	NAC-LWT	1040°C (40 min)	279°C	570°C
	NAC-LWT (ISO Container)	1040°C (40 min)	284°C	570°C
MacArthur Maze [113]	GA-4	1100°C (37 min) 900°C (71 min)	753°C	592°C
Newhall Pass¹ [114]	GA-4	1016°C (78 min)	534°C	559°C

Note:

1. The Newhall Pass fire was analyzed for a series of potential fire scenarios. The maximum sheathing temperature is based on a 78-minute fire with a peak temperature of 1016°C.

There are three primary outcomes from a severe fire in an enclosed area. First, the lid seals can remain below their rated operating temperature, in which case there is no release of radioactive material. This is the most common result in an open (non-enclosed) pool fire. Second, the seals fail, but the cladding remains intact. There could be a minor release originating from the CRUD (i.e., corrosion products) on the surface of the used fuel sheathing. Third, the temperatures are high enough that both the package lid seals fail and the sheathing rupture temperature is exceeded. In this case, there can be a small release originating from the CRUD on the surface of the used fuel sheathing as well as very small particulates from the used fuel. The most probable outcome in the second and third cases is that there is no release given the small clearance between the lid and package body. These clearances remain small enough that they can be easily blocked or plugged by any particulates entering the clearance. Table L-5 shows the results from the Caldecott Tunnel, MacArthur Maze and Newhall Pass fires.

Table L-5: Results from accidents involving fires in enclosed spaces

Accident	Package	Seal Temperature Exceeded	Sheathing Temperature Exceeded	Source of Release	Estimated Release TBq	Fraction of Release Allowed by the Regulations A ₂
Caldecott Tunnel [112]	NAC-LWT	x		CRUD adhering to fuel pin surface	0.0004	0.001
MacArthur Maze [113]	GA-4	x	x	Particulates released by sheathing rupture	0.91	0.24
Newhall Pass [114]	GA-4	x	x	Particulates released by sheathing rupture	0.91	0.24

The package seal temperature for the NAC-LWT for the Caldecott Tunnel accident scenario exceeds its operating limit, but the fuel sheathing remains intact. The release was estimated to be on the order of 0.0004 TBq which is about one-tenth of the amount that the regulations allow per week.²⁷ Both the seal temperature and sheathing rupture temperature are exceeded in the MacArthur Maze and Newhall Pass fires. The release for these scenarios is estimated to be on the order of 0.91 TBq, which is about 25% of the amount that the regulations allow per week.

Based on these results, the possibility of a small release from the UFTP cannot be ruled out. The Dry Storage Container Transportation Package (DSC-TP) would not suffer a release because of its welded lid. This conclusion for the UFTP is based in part on the packages having a similar mass, (i.e., thermal inertia) as the packages evaluated in the Caldecott Tunnel, MacArthur Maze and Newhall Pass fires. Also, the sheathing rupture temperature reported for used CANDU fuel is approximately 650°C, which falls within the range of maximum sheathing temperatures calculated for the MacArthur Maze and Newhall Pass fires [101].

L.2.4 Summary

Neither the impact or puncture force that occurred in the James Snow collision would be sufficient to either breach the package walls or severely damage the package's sealing areas of the DSC-TP or UFTP.

A small release could be possible for the UFTP if the package seal operating temperature and fuel rupture temperature are exceeded in a severe fire. This could occur in an enclosed fire, such as one that might occur in a road tunnel or highway underpass. The package seal operating temperature and fuel rupture temperatures are unlikely to be exceeded in fires that occur in unenclosed areas such as open pool fires.

²⁷ The allowable release for a Type B package is A_2 per week.

APPENDIX M LAC MÉGANTIC TRAIN DERAILMENT

M.1 THE ACCIDENT

The Lac Mégantic train derailment was a railway accident that occurred during the early hours of July 6, 2013, in Lac Mégantic, Québec, Canada. The accident involved a Montréal, Maine and Atlantic Railway freight train carrying approximately 6.7 million liters of petroleum crude oil in 72 tank cars. At the point of derailment, the train was traveling about 105 km/h. Sixty-three of the 72 tank cars derailed spilling approximately 6 million liters. A schematic of the accident is shown in Figure M-1.

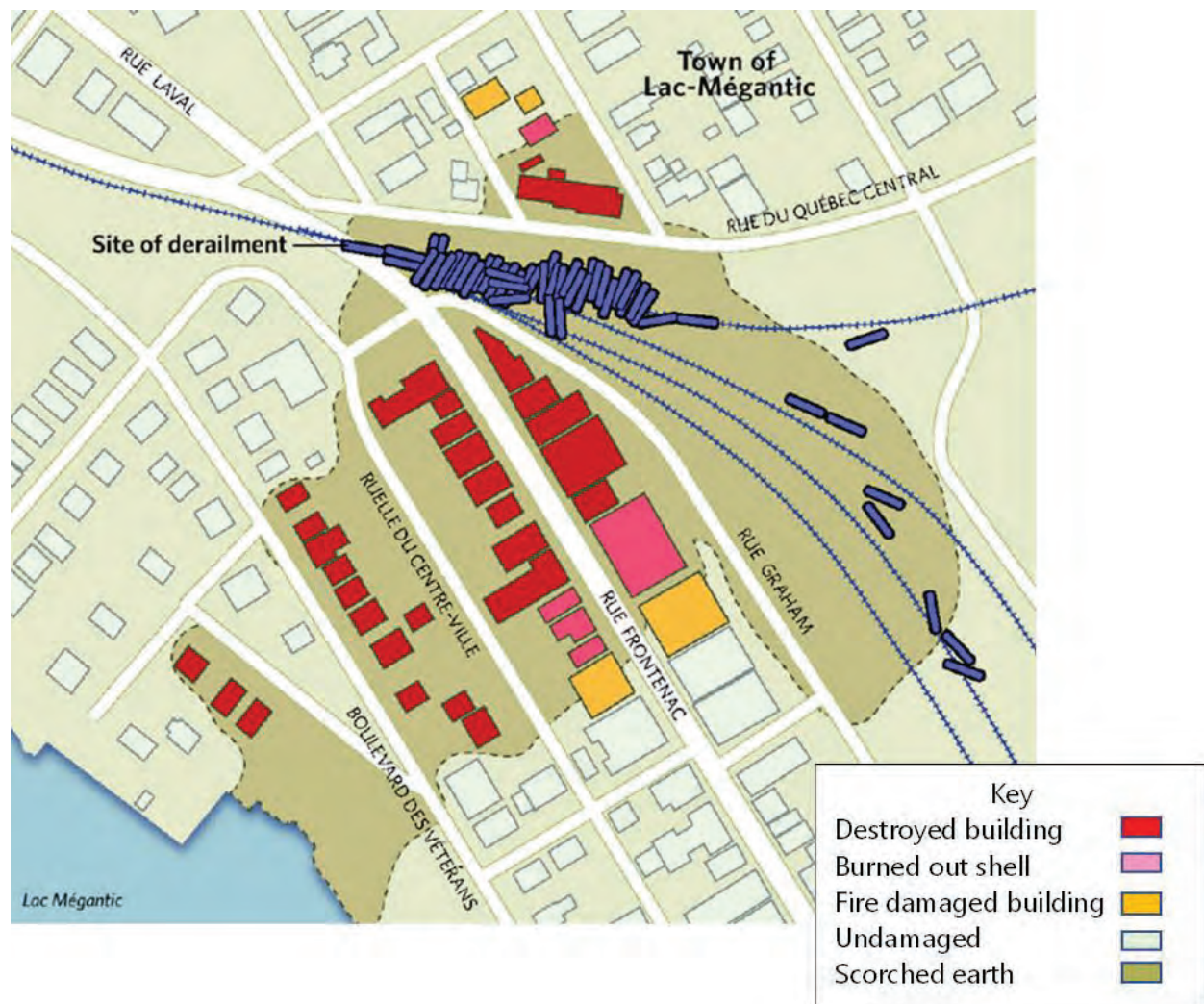


Figure M-1: The Lac Mégantic accident

Crude oil flowed downhill away from the derailment site towards the center of Lac Mégantic, with some of the crude oil entering manholes and flowing through the town's storm sewer system. An estimated 100 000 liters of crude oil ended up in Mégantic Lake and the Chaudière River by way

of surface flow and the town's underground sewer system. As a result of the derailment and ensuing fires and explosions, 47 people died and about 2000 people were evacuated. Forty buildings and 53 vehicles were destroyed.

M.2 POTENTIAL IMPACT ON A USED NUCLEAR FUEL PACKAGE

Several aspects must be considered when evaluating the performance of a used fuel package, such as the Dry Storage Container Transportation Package (DSC-TP), in accidents such as the Lac Mégantic train derailment. These include the potential damage to the package body or lid welded closure area from (1) direct impact, (2) puncture, (3) explosions and (4) long duration severe fires. The release of radioactive material will only occur if the DSC-TP side wall and DSC-TP container side wall is breached, or the welded closure area is severely damaged.

M.2.1 Direct Impact

It was estimated that the train was going approximately 105 km/h (65 miles/h) when it derailed. This speed represents an upper bound on impact speed. The effective speed of impact for a UNF package would probably be much lower than 105 km/h because of the reduced speed at which some cars derailed, and the orientation of the package during impact. The speeds at which the tank individual cars derailed were predicted in the official accident report and are shown in Figure M-2.

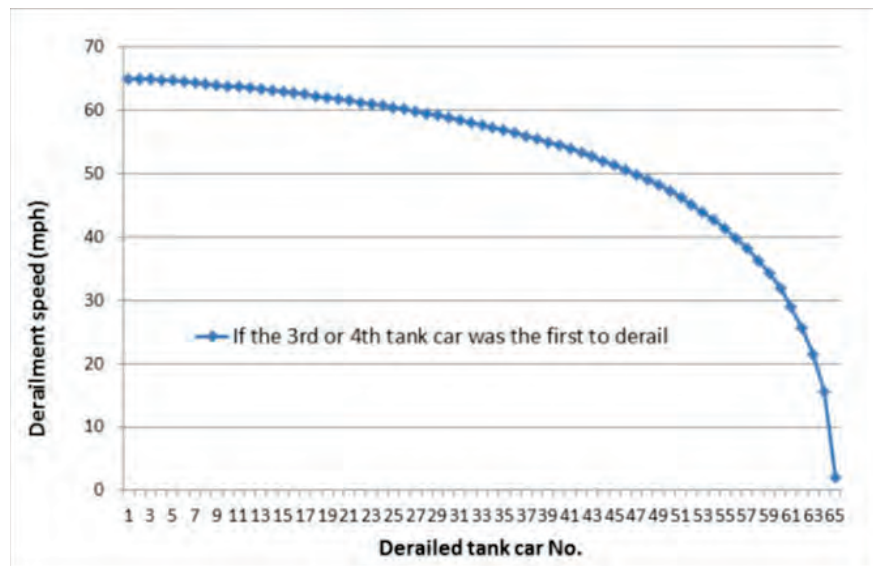


Figure M-2: Estimated speed of impact of derailed tank cars [94]

The derailment speeds ranged from 105 km/h to 5 km/h and decreased with distance from the first derailed car. In addition, the impact to a DSC-TP would most likely result from the DSC-TP colliding with an adjacent railcar, most likely in a side-to-side impact. This results from the tendency of railcars to end up in accordion-like patterns in derailments. The accordion-like pattern can be seen in Figure M-3.



Figure M-3: Lac Mégantic accident aftermath

In addition, some of the impact force would be absorbed by the used fuel package transport railcar. Unlike tank railcars, used fuel packages are attached to the railcars using tie-downs. (Figure M-4). The SANDIA tests, described in Section 4.2, are an example of the ability of used fuel package railcars to absorb the forces of direct impact. The impact limiters for the DSC-TP also provide protection to the lid area during impact, and the side protection shield provides additional resistance to a side impact. The body of the DSC-TP is approximately 54.9 cm thick. (i.e., a 52.3 cm concrete shell encased in two 1.27 cm carbon steel shells). The lid is sealed using multiple weld passes.



Figure M-4: Tank railcar (left) and used fuel railcar (right) – note that the DSC-TP is shipped horizontally

The impact forces experienced by the DSC-TP during the Lac Mégantic train derailment would be several orders of magnitude lower than the forces measured in the 160 km/h train collision described in Operation Smash Hit (described in Section 4.3). Operation Smash Hit simulated a rail accident that consisted of a 140 metric ton locomotive traveling at 160 km/h colliding directly with a stationary 47 metric ton Magnox flask attached to a 13 metric ton railcar. The flask and railcar were oriented so that the locomotive would strike directly on the package lid edge at the most vulnerable orientation. The orientation of the flask was chosen to represent the most vulnerable location, near the lid seal region which consisted of a bolted lid and O-rings. The full-scale simulation demonstrated that Magnox package could survive a severe rail accident with

surficial surface damage, minimal damage to the lid seal region, and no significant release of radioactive material.

In comparison, the DSC-TP is a heavier package (100 tons when loaded), and has welded lids. The impact speeds and forces during the Lac Mégantic derailment (which derailed at 80 km/h) are much smaller than the forces involved in a direct collision of a locomotive traveling at 160 km/h (such as Operation Smash Hit). The impact forces on the DSC-TP that would have occurred during the Lac Mégantic train derailment would be not be sufficient to either breach the package wall or severely damage the package's welded closure area.

M.2.2 Puncture

The DSC-TP has thick walls that are made of carbon steel encased concrete. The total wall thickness consists of a 52.3 cm (20.6 in) thick layer of concrete encased by two 1.27 cm (0.5 inch) thick carbon steel shells. The 52.1 cm (20.5 in) thick package lid consists of concrete encased in a carbon steel shell. The top and bottom of the package are protected by polyurethane foam impact limiters encased in stainless steel shells. The DSC-TP uses double layered side protection during transportation. The side protection consists of two layers – an inner stainless steel shell that is 1.3 cm (0.5 in) thick and an outer stainless steel shell that is 0.95 cm (0.375 in) thick. The shells extend downward from the top impact limiter and upward from the bottom impact limiter and overlap around the circumference of the DSC-TP.

Data from the U.S. Nuclear Regulatory Commission (NRC) and Association of American Railroads (AAR) (presented in Section 3.2.1.3) show that rail tank cars with thicknesses greater than one inch are highly unlikely to be punctured in severe rail accidents. The puncture forces on the DSC-TP that would have occurred during the Lac Mégantic train derailment would be not sufficient to either breach the package wall or severely damage the package's welded closure area.

M.2.3 Explosion

No BLEVEs occurred in the Lac Mégantic train derailment because the crude oil in the tank car had a boiling point well above ambient temperatures. This was confirmed in the official accident report based on the lack of tank car fragments at the accident site [94]. The explosions that were reported would have resulted from the detonation of vapor clouds (vapor cloud detonation (VCD)). The blast waves from VCDs are of the same general magnitude as those occurring during BLEVEs.

One study with particular relevance to the Lac Mégantic train derailment is the physical demonstration test of a propane tank car boiling liquid expanding vapour explosion (BLEVE) next to a CASTOR THTR/AVR used fuel package conducted by the German Federal Institute for Materials Research and Testing (BAM) [103]. The demonstration test is described in more detail in Section 4.4.1.

During the test, the propane tank BLEVE resulted in a severe impact of rail tank car fragments with the CASTOR package and caused the 22 450 kg package to be flipped over, landing 7-10 meters from its original location. The BLEVE caused only superficial damage (deep scratches and imprints from the impacting railcar fragments) to the package body and did not significantly affect the integrity of the package's bolted lids. The integrity of the package's lids was confirmed as the measured leak rates from the lid seals was the same before and after the accident. The impact on the package was determined to be on the same order of magnitude from the regulatory drop test (9 meters onto an unyielding surface).

In comparison, the DSC-TP is a heavier package (100 tons when loaded), and has a welded lid. The impact forces from a BLEVE during the Lac Mégantic would be similar to those experienced in the BAM test since they both involved exploding propane tanks. The impact forces on the DSC-TP that would have occurred during from a BLEVE in the Lac Mégantic train derailment would not be sufficient to either breach the package wall or severely damage the package's welded closure area.

M.2.4 Fire

The fires that occurred during the Lac Mégantic derailment were caused when crude oil released from ruptured tank cars ignited. The resulting fires were widespread, burning both at the site of the derailment and at multiple locations within the town of Lac Mégantic, engulfing buildings and other structures. Most of the crude oil that was spilt flowed downhill through the streets and underground sewer system. Eventually over 100 000 liters reached the Mégantic and the Chaudière River.

The impact of the fire on the DSC-TP is determined by its location in the fire. As a condition of approval, the DSC-TP was evaluated in a fully engulfing fire – this means that 100% of the package surface is exposed to the fire's heat flux. From the accident photos (Figure M-3) of the Lac Mégantic train derailment, it is evident that if a UNF package was in the derailment it would be shielded from much of the fire by adjacent tank cars. In addition, the transport vehicle would likely shield one side of the DSC-TP from fire exposure.

The package may also come to rest on the ground, in which case it would reduce the surface area exposed in an accident as compared to the fully engulfing fire required in the regulations. The lid area is also encased by impact limiters that act as insulators or heat shields.

Given the large thermal inertia of the 100 metric ton DSC-TP, and the fact that the fire would not be fully engulfing, the DSC-TP would be unlikely to experience temperatures that would adversely affect the integrity of the package body or lid seal region.

M.2.5 Summary

None of the impact forces (impact, puncture and explosion), or the fire that occurred in the Lac Mégantic train derailment would be sufficient to cause either a breach in the DSC-TP package wall or severely damage the welded closure area.

Appendix E – Transportation Collision Data Analysis Report

Title: <i>UFTS Transportation Collision Data Analysis Report</i>		External Document No.: 60686264	Revision: 000
Company Name: <i>AECOM Canada Nuclear Services Ltd.</i>			
NWMO Document No.: APM-REP-04240-0201	Revision: 000	NWMO P.O. No.: 2001513	
Date Submitted: <i>2023/08/31</i>		Page: Approval Cover Sheet	

Used Fuel Transportation System – Transportation Collision Data Analysis Report

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Used Fuel Transportation System Transportation Collision Data Analysis Report

Nuclear Waste Management Organization (NWMO)

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Appendix A – Conditional Probabilities for Incidents involving Truck Tractors

Appendix B – Conditional Probabilities for Incidents involving Trains

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List of Acronyms and Abbreviations

AEBS	Advanced Emergency Braking System
AECL	Atomic Energy of Canada Ltd.
APM	Adaptive Phased Management
CITS	Cooperative Intelligent Traffic Systems
CN	Canadian National Railway
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
CP	Canadian Pacific Railway
DGAIS	Dangerous Goods Collision Information System
DGR	Deep Geological Repository
DSC-TP	Dry Storage Container Transportation Package
EITS	Event Information and Tracking System
EU	European Union
FEA	Finite Element Analysis
GRS	Gesellschaft fuer Anlagen-und Reaktorsicherheit
HAC	Hypothetical Accident Conditions
HGV	Heavy Goods Vehicle
HLW	High-Level Radioactive Waste
HSM	Highway Safety Manual
IAEA	International Atomic Energy Agency
KM	Kilometre
LLNL	Lawrence Livermore National Laboratory
MTO	Ministry of Transportation Ontario
MTQ	Québec Ministry of Transportation
MVA	Motor Vehicle Accident
NCT	Normal Conditions of Transport
NWMO	Nuclear Waste Management Organization
OPG	Ontario Power Generation
PATRAM	Packaging and Transportation of Radioactive Materials
PPE	Personal Protective Equipment
PDO	Property Damage Only
PIN	Product Identification Number
PTNSR	Packaging and Transport of Nuclear Substances Regulations
RODS	Rail Occurrence Database System
SAAQ	Québec Automobile Insurance Company
SMV	Single Motor Vehicle
SNF	Spent Nuclear Fuel
TC	Transport Canada
TDG	Transportation of Dangerous Goods
TSB	Transportation Safety Board (of Canada)
U.S.	United States
USNRC	United States Nuclear Regulatory Commission

Terms and Definitions

Artificial Dawn/Dusk	In terms of lighting conditions for vehicular collisions, artificial dawn/dusk refers to the lighting conditions normally occurring between half an hour before and half an hour after sunrise/sunset, with artificial illumination functioning at the collision site.
Collision	An unexpected and unintentional event that results in damage or injury. For this report, the event involves a large truck or train, resulting in subsequent “collision” and “non-collision” events.
Collision with a fixed object	Encompasses collisions with fixed objects, such as bridges structures, trees, guide rails, rocks, ditches, etc.
Collision with a non-fixed object	Encompasses collisions with moving objects, such as another vehicle, trains, animals, pedestrians, cyclists, etc.
Collision Rate	The ratio between the number of collisions that happened in a given time period (e.g., year) and a baseline statistic over that same period (e.g., kilometres travelled). The collision rate estimates the collision occurrence per unit of measurement (e.g., collisions per kilometre). In roadway safety studies, traffic volume, measured as million vehicle kilometres, can be used to calculate the collision rate.
Conditional Probability	Conditional probability is defined as the likelihood of an event or outcome occurring based on the occurrence of a previous event or outcome. Conditional probability is calculated by multiplying the probability of the preceding event by the updated probability of the succeeding or conditional event.
Event Tree	An event tree is an inductive analytical diagram that analyzes an event using Boolean logic to examine a chronological series of subsequent events or consequences.
Heavy Goods Vehicle	A transport truck/trailer in the European Union, with a gross combined weight of 3,500 kg, including cargo, also known as a large goods vehicle (LGV).
Motor Vehicle Accident	A motor vehicle accident is an accident that involves a collision with another motor vehicle(s) (as defined in Canadian Nuclear Safety Commission (CNSC) data).
Non-collision Event	Encompasses those incidents in the Ontario’s collision database that cannot be labelled as collisions with fixed or non-fixed objects, such as fire/explosion, load spill, skidding/sliding, ran off road, rollover, and jack knifing.
Probability	A probability is a number that reflects the chance or likelihood that a particular event will occur. Probabilities can be expressed as proportions that range from 0 to 1. They can also be expressed as percentages ranging from 0% to 100%.
Property Damage Only (PDO) Collision	Regarding collision severity, a “property damage-only collision” is a collision without injury or fatality.
Single Motor Vehicle (SMV) Collision	In terms of collision impact type, collisions that only involve one operating vehicle in which the operating vehicle collides with one or more fixed objects or unattended vehicles (i.e., vehicles that are not under the care and control of a driver, such as parked, stopped, disabled, abandoned, and runaway vehicles).

Screening Criteria	Data elements (e.g., contributing factors) in the overall dataset are examined to determine the element's effect on the interpretation of results from statistical models.
Train Accident (Collision)	Train accident is an event in which the involved train collides with other objects (e.g., other trails, vehicles, fixed objects, lifeforms), derails, catches fire or explodes (as defined in Transportation Safety Board Data).
Train Derailment	Any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to track or equipment.
Train Incident	Train incident is an event with a risk of collision, but no collision occurred (as defined in Transportation Safety Board Data).
Truck Tractor	A motor vehicle is designed to draw a trailer and is not constructed to carry a load other than what is drawn behind the vehicle.
Type B Package	Type B packages are used to transport materials with high levels of radioactivity, such as spent nuclear fuel, high-level radioactive waste, or high-radiation sources. These packages are typically large and heavy; designed and tested to provide adequate containment and shielding when subjected to normal conditions of transport and under hypothetical accident conditions set forth in regulations (i.e., pass stringent impact, drop and puncture tests, an engulfing fire test, and immersion in water). In Canada, these packages are certified by CNSC.
Used Nuclear Fuel	Used fuel assemblies removed from a reactor after several years of use. The fuel is a solid material in the form of ceramic pellets contained within tubes made of corrosion-resistant zircaloy.

1 Executive Summary

Why was this study completed?

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. NWMO's plan calls for used nuclear fuel to be safely contained and isolated in a deep geological repository (DGR), consistent with international practice. Currently, two candidate communities are being considered to host the DGR. One is in the Wabigoon Lake Ojibway Nation-Ignace area in Northwestern Ontario, and the second is in the Saugeen Ojibway Nation-South Bruce area in Southern Ontario. A final decision regarding the site for the DGR is expected by the end of 2024.

Transporting used nuclear fuel raises many concerns and queries by members of the public and interested parties as they relate to collisions and potential impacts.

The transportation of used nuclear fuel from interim storage facilities located in Ontario, Quebec, and New Brunswick to the centralized DGR location will be required.¹ However, while there is a strong international track record regarding the shipment of radioactive materials, these shipments understandably raise concerns and queries from the public and interested parties regarding potential incidents or collisions during transport.

This study statistically analyzes and assesses collision data from provincial resources to understand the types of collisions, severity, and potential causes of collisions and to quantify transport collision probabilities based on this information.

This study aims to gather, analyze, and assess available collision data relevant to the modes (road and rail) and types of conveyances proposed to transport used fuel to the DGR. This study statistically analyzes and assesses collision data to understand the types of collisions, severity, and potential causal factors, as well as to quantify transport collision probabilities based on this information. Collision probabilities, patterns, and trends identified in this report will feed into future analyses, which will explore

potential preventative and mitigating measures that can be leveraged to reduce the likelihood of transportation collisions. These potential mitigation measures and other good practice operational protocols are discussed in detail in the NWMO Transportation Mitigation Report.

This report intends to analyze historical collision conditions which may apply to road and rail conveyances which NWMO is considering for transporting Type B² packages. Using incident and collision data and applying probabilistic assessment methods, collision probabilities are calculated. This report's analyses are generic in nature and not specific to any particular route. Furthermore, these analyses do not assess the likelihood that a collision could lead to a potential consequence (e.g., breach of a Type B package) or potential impact (e.g., environmental impacts, health effects, or injuries). Additionally, the analyses do not consider any security threats or malicious actions.

One of the primary goals of this study is to identify emerging themes that may be of interest to communities and members of the public regarding safety risks associated with transporting radioactive materials using Type B packages.

¹ Used fuel from Whiteshell Laboratories (Manitoba) is anticipated to be consolidated at Canadian Nuclear Laboratories (Ontario) prior to the start of NWMO transportation operations.

² Type B packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions such as drops, fires, and immersion in water. Type B packages are commonly used to transport used nuclear fuel by road, rail, and water modes of transport.

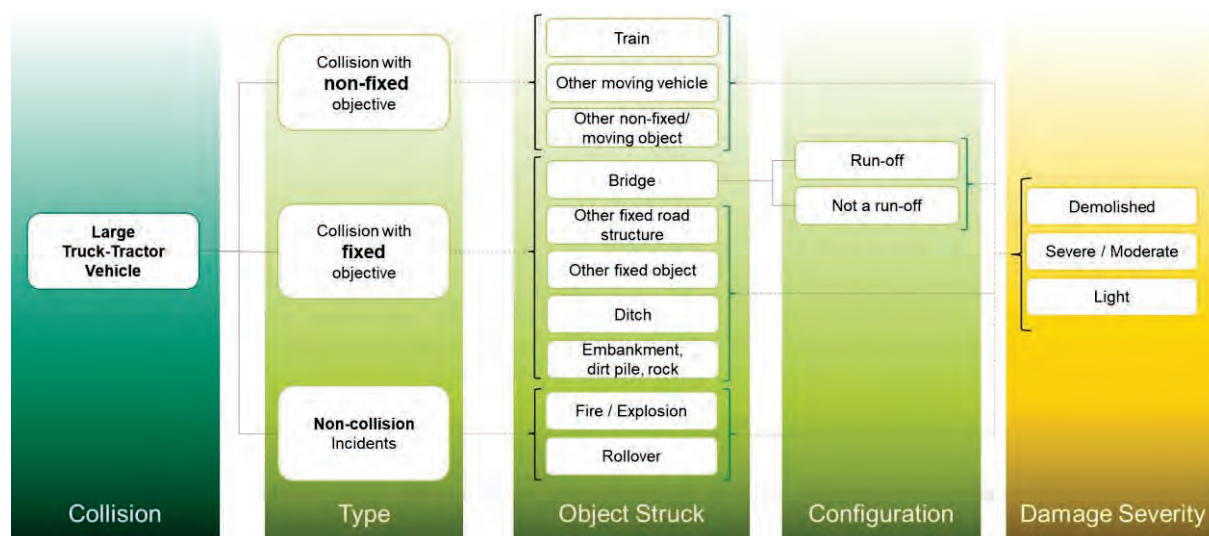
Overview of the methodology

The Used Fuel Transportation System Collision Data Analysis began with a review of available literature to examine (1) historical information on the transportation of spent nuclear fuel statistical and risk analysis and (2) methods used to examine statistical probabilities of road and rail collision scenarios. The literature review identified multiple references describing the exemplary history of spent nuclear fuel transportation and detailing the very low probability of a collision involving road or rail transportation resulting in a radiological dose to a member of the public above regulatory limits.

Additionally, several documents presented similar methodologies of determining the probabilities of specific collision or collision scenarios resulting in various levels of damage to the involved transport vehicles. The common feature of these analyses was using "event trees" for calculating the probability of a series of events. Visually, an event tree displays an event path that starts with the initiating event (trunk of the tree). This then leads to following events like the branch of a tree, and then to the next event, and so on.

Ultimately, an event tree maps out the completely defined collision event scenario in a causal format. When analyzed collectively, the event tree describes the potential outcomes of an initiating event. **Figure ES-1** shows an example of an event tree for truck movements without event probabilities.

Figure ES-1: Example of an Event Tree³



The approach for identifying collision types and calculating respective probabilities is based on comprehensive road and rail event data for the conveyances being considered by NWMO for the transport of used fuel. As part of the analyses, collision datasets from different resources, discussed below, were reviewed in detail.

A key study objective was to collect suitable data on which a robust probabilistic assessment may be based. As such, it was determined that ten (10) years of historical collision data from 2010 to 2019 pertaining to relevant road and rail conveyances within the geographic study area would prove suitable.

Following a qualitative and quantitative analysis of the collision data, a breakdown of the percentage of collisions involving conventional shipments by truck and train and those involving dangerous goods by type was prepared. Next, potential screening criteria were identified through a review of similar assessments to understand the nature of the type of collisions that apply to the transport of Type B packages. Screening criteria refer to certain parameters which may be applied to isolate the relevant portion of the dataset utilized for the probabilistic assessment study.

³ Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Accidents on Canadian Roadways (Lloyd's Register, 2019)

For the purpose of this study, the road portion of the analysis focused on datasets of truck-tractor collision data as this is the type of conveyance that may be used to transport Type B packages by NWMO. The rail portion of the study did not contain train operators' actions and conditions. As such, no screening criteria were applied to pare down the dataset to make it more representative of Type B package transportation.

The next step after identifying screening criteria was to develop event trees to illustrate the possible list of collision scenarios and their resulting probabilities. The probability of a particular collision scenario is calculated as the product of all the branch point fractions on the scenario path. In other words, the probability of a particular collision scenario is the product of the probabilities of all events described in the scenario set out in the event tree. It is important to note that the calculated probabilities refer to a particular collision scenario that assumes a collision has already occurred.

How were key findings derived?

The approach for identifying collision types and calculating incident probabilities is based on a comprehensive review of road and rail event data and the class of highway most likely to be used for the transportation of used nuclear fuel. The data gathered by the following primary sources were utilized to develop collision scenarios and their resulting probabilities, separated for truck and train movements:

- Truck datasets:
 - Ontario Ministry of Transportation (MTO)
 - Québec Ministry of Transportation (MTQ) / Québec Automobile Insurance Company (SAAQ)
 - New Brunswick Transportation and Infrastructure
 - Transport Canada's Dangerous Good Accident Information System (DGAIS), which contains reports provided at the time of a collision if a release (or anticipated release) of the dangerous goods endangers (or could endanger) public safety
 - Canadian Nuclear Safety Commission's Event Information and Tracking System (EITS)
- Train dataset:
 - Transportation Safety Board of Canada (TSB)

The incident data derived from these sources was then segmented into the following categories:

- Transport of dangerous goods vs conventional shipments
- Collision data pertaining to conveyances capable of transporting Type B packages
- Delineation of truck tractor combination vehicle incidents by multiple road types, incident cause, and driving conditions

What are the historical trends?

Used nuclear fuel is transported within and between global jurisdictions. The **U.S. Department of Energy** examined the history of worldwide used fuel transportation⁴. This study concluded that worldwide transportation of used fuel has been accomplished routinely and safely for decades.

It reported that, historically, collisions have been infrequent in used fuel and high-level radioactive waste transportation. When collisions have occurred, most have been minor collisions such as low-speed derailments or minor traffic collisions with little or no damage to the package being transported.

Collisions involving radioactive material in Type B packages can occur.

However, there has thus far been no loss of contents, no loss of life, and no impact on the environment caused by the radioactive nature of the material transported within Canada.

⁴ DOE 2016. U.S. Department of Energy Nuclear Fuels Storage and Transportation Planning Project. A Historical Review of the Safe Transport of Spent Nuclear Fuel. FCRD-NFST-2016-000474, Rev. 1. ORNL/SR-2016/261, Rev. 1

Specifically, the study showed that at least 25,400 shipments of used fuel were made worldwide between 1962 and 2016. All of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported. The worldwide number of Type B package shipments is far greater than used fuel shipments (e.g., approximately 255,000 shipments from 1979 through 1982) and was seen to feature a similar safety record.

What are the key findings?

1. Historically, there have been very few collisions in Ontario, New Brunswick and Québec involving road transport of radioactive materials.

Data for collisions during road transportation of dangerous goods, and specifically Class 7 (radioactive) material, in Canada were analyzed. The *Canadian Nuclear Safety Commission (CNSC)* indicates that 492 Class 7 transportation incidents were reported to the CNSC between 2000 and 2022. Of these, 58 incidents involved Type B transportation packages, none of which involved a loss of contents. In addition, none of the recorded incidents involved contents classified as used nuclear fuel.

In Ontario, between 2010 and 2019, 98 out of 38,296 truck-tractor collisions (less than 0.3% of truck-tractor collisions) in Ontario provincial highways involved dangerous goods. Of those 98 recorded collisions involving dangerous goods, only one incident (0.01%) involved a vehicle carrying Class 7 dangerous goods (radioactive materials). In New Brunswick, during the same time period, 27 out of 2,972 reported truck-tractor collisions (less than 1% of truck-tractor collisions) involved vehicles carrying dangerous goods. None of the 27 recorded incidents involving dangerous goods included vehicles carrying Class 7 dangerous goods (radioactive materials). In contrast to Ontario and New Brunswick, the Québec database did not provide a breakdown of the number or the type of dangerous goods carried by trucks in Québec.

For the years 2012 to 2021 inclusive, 1,456 incidents involving dangerous goods were reported by Transport Canada. Of these, 302 incidents were recorded for the provinces of Ontario (177), Québec (113), and New Brunswick (12). It is noted that the numbers reported in the DGAIS data do not necessarily match the provincial numbers discussed in earlier sections. Of those 302 incidents, one event (0.003%) related to Class 7 substances (radioactive materials) and did not result in the release of radioactive material.

2. The probability of a sequence of events occurring involving truck tractors capable of transporting a Type B used nuclear fuel package that could result in severe damage or complete demolition of the conveyance is very low.

The conditional probabilities for all truck collision scenarios were calculated using the event tree described above and the probabilistic analysis conducted as part of this project. Next, all truck tractor collision scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

The conditional probabilities of scenarios for truck tractors carrying dangerous good materials with vehicle damage severity of "demolished" or "severe/moderate damage" ranged from 3.41×10^{-4} to 1.94×10^{-8} . In terms of conditional probabilities, the probability of these scenarios occurring ranged from 1 in 2,930 to 1 in 51,501,511 if a truck collision occurred in the first place. These statistics show that the conditional probabilities of truck-tractor collisions carrying dangerous goods with vehicle damage severity of "demolished" or "severe/moderate damage" are very low.

3. There have been very few incidents involving rail transport of dangerous goods.

In contrast to multiple data sources for truck collisions, the TSB database was considered the only source of information about train collisions in Canada that could be utilized to calculate probabilities. While the TSB database indicates that train collisions involving the release of dangerous goods do occur, it was found that of the 11,013 train collisions analyzed between 2010 and 2019, only 48 collisions (0.5%) pertained to a release of dangerous goods into the environment).

4. The probability of a sequence of events occurring involving rail transportation that could result in severe damage or complete demolition of the conveyance is very low.

Like truck movements, the train event tree was utilized to calculate the conditional probabilities for all train collision scenarios. All train collision scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

The conditional probabilities of scenarios for trains carrying dangerous good materials and breach of materials ranged from 3.47×10^{-4} to 4.68×10^{-6} . In terms of conditional probabilities, the probability of these scenarios occurring ranged from 1 in 2,884 to 1 in 213,533 *if* a train collision occurred in the first place. As can be seen from these statistics, the conditional probabilities of train collisions carrying dangerous goods with breach of materials are very low.

5. Certain transportation conditions can lead to a greater probability of a collision involving truck tractors capable of transporting a Type B used nuclear fuel package.

Contributing factors for collisions involving truck tractors were derived from the Ontario, Québec, and New Brunswick datasets. Overall, when comparing the percentages between Ontario and New Brunswick, similar trends in driver actions and driver conditions were observed for most of the contributing factors, which included inattentive drivers and winter weather/road conditions. Of all truck tractors involved in collisions between 2010 and 2019, close to 20% were involved in collisions on icy/snow/slush surface conditions. 38% of these collisions resulted in vehicle damage categorized as severe/moderate damage, while 6% resulted in vehicle damage categorized as demolished. In contrast, considering all truck tractors involved in collisions (all road conditions), the fraction of those incidents which resulted in a vehicle damage severity that was categorized as severe/moderate or demolished damage was 28% and 4%, respectively.

Additional Conclusions

The analysis provided in this report supports that truck and rail collisions involving radioactive materials (in particular, Type B packages) occur so infrequently that there is insufficient data on which to base a robust statistical analysis specific to these types of transport. Therefore, one must use conventional truck/train collision statistics to construct a data set with a population size sufficient to draw meaningful conclusions on collision probabilities and causal factors.

The road collision datasets used in this analysis are sufficiently large, and the resulting collision probabilities and causal factors map well against previous analyses carried out in Canada as well as internationally.

Additionally, conclusions regarding collision causal factors are reliable enough on which to base future mitigation and control measures. A follow-up report addresses the practices, factors, and technologies that may be useful for addressing causal factors related to transportation collisions for conveyances capable of transporting Type B used nuclear fuel packages.

2 Introduction

2.1 Background

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. Canada's plan for managing used nuclear fuel is known as Adaptive Phased Management (APM). It consists of isolating and containing used nuclear fuel in a Deep Geological Repository (DGR) using a multiple barrier system in a robust host geology.

Canada's used nuclear fuel is currently safely stored on an interim basis in licensed facilities at reactor sites in Ontario, Québec, and New Brunswick, as well as at Atomic Energy of Canada Limited's (AECL) nuclear research laboratories in Ontario and Manitoba. Managing all of Canada's used nuclear fuel in a single repository location will require the transport of used nuclear fuel from these interim storage facilities to the centralized DGR location.

NWMO is currently in the process of identifying a willing and informed host community and region for the APM DGR. The Township of Ignace and Wabigoon Lake Ojibway Nation in Northwestern Ontario, and the Municipality of South Bruce and Saugeen Ojibway Nation in Southern Ontario, are potential host areas for the project. Site selection is currently expected to occur in late 2024. The interim storage sites and candidate DGR sites are outlined in **Figure 1**.

Figure 1: Overview of Existing Interim Storage and Candidate DGR Sites



NWMO's responsibility in spent nuclear fuel management includes designing and developing a transportation system for the safe and secure delivery of used fuel from current interim storage facilities to the DGR. Current plans are to begin operation of a repository facility no sooner than 2043. Once a facility is constructed and licensed, used fuel will be transported from the existing interim storage sites to the repository by road and/or by rail.

The objective of this report is to gather, analyze and assess available accident data relevant to modes and types of conveyances proposed to transport NWMO's used fuel. The purpose of this report is to statistically analyze and assess accident data to understand types of accidents, severity and potential causes of accidents and to quantify transport accident probabilities for two key reasons:

1. To respond to concerns and queries brought up by members of the public and interested parties as they relate to accidents and potential impacts associated with these types of shipments, and,
2. To inform and identify potential mitigating measures which can reduce the likelihood of transportation accidents.

The analyses presented in this report are generic in nature (not route specific) and the analyses do not consider environmental impacts, health effects or injuries resulting from an accidental collision or purposeful security/malevolent acts.

2.2 Objective of the Report

The 'Used Fuel Transportation System's Transportation Collision Data Analysis Study' was prepared by AECOM Nuclear Services Ltd for NWMO's use in addressing the specific needs of the project and their business.

NWMO commissioned the work described in this report in response to queries brought up by interested parties regarding the risk of collisions⁵ during the transportation of used nuclear fuel.

This report considered specific issues raised by Canadians and Indigenous peoples related to the types of collisions people are concerned about. One of the objectives of this work is to respond to those concerns at this early stage, acknowledging that the NWMO is still approximately 20 years away from transporting used nuclear fuel to the future DGR.

The Transportation Collision Data and Mitigation Assessment aims to expand upon existing transportation analyses outlined in **Section 4.7 Previous Applications** and provide a specific evaluation of collision types and probabilities for vehicles associated with the transport of Type B transportation packages as outlined in **Section 2.1 Background**.

This entails an analysis of both road and rail transportation in Canada. The conclusion of the work will:

- Quantitatively assess the collision probabilities associated with types of conveyances which may be used by NWMO to transport of Type B packages,
- Establish bounding collision scenarios that could have the potential to translate into damage to and releases of radiation from Type B packages, and
- Establish potential collision mitigation methods that can be implemented within NWMO's transportation program (including conveyance, equipment inspection, maintenance, and operational and administrative controls).

To meet the project objectives, the scope of work has been organized into three distinct and integrated Work Packages which focus on the following:

- **Work Package # I: Collection and analysis of existing relevant collision data,**
- **Work Package # II: Development of event trees and collision probabilities and**
- **Work Package # III: Identification and assessment of mitigation measures that can reduce risks.**

This report encompasses the work completed in Work Packages # I and # II.

The consequences (breach of a Type B transportation package) or potential impacts (environmental impacts, health effects or injuries) of collisions are not considered within the scope of this assessment.

⁵ It should be noted that the accepted industry standard and road safety term refers to collisions rather than accidents. The term 'accident' implies that no one is at fault and that no one, including the driver, bears responsibility for the outcome. The term 'collision', on the other hand, is more specific in terms of the action's outcome without the unpreventable implication.

Such analyses, typically referred to as ‘risk assessments’ or ‘consequence analyses’, may be conducted in the future utilizing the results of the current report as input for expected initial conditions.

This report intends to analyze historical collision conditions which may apply to road and rail conveyances which are being considered by NWMO for transporting Type B packages. This report does not present the hypothetical consequences which may arise as a result.

Similarly, this assessment does not aim to quantify the radiological dose from incident-free transport of Type B transportation packages. This assessment aims to provide an improved understanding of vehicle collision scenarios that could impact the safe movement of conveyances transporting Type B packages for both road and rail modes of transport.

Using incident and collision data and applying probabilistic assessment methods, event trees and collision probabilities for scenarios of varying severity are to be defined. Following this analysis, mitigating actions will be identified in a separate report under Work Package # III to inform NWMO’s future program procedures aimed at reducing or eliminating risks based on potential collision severity levels and probabilities of occurrence.

2.3 Context

2.3.1 Radioactive Material Transportation

The transportation of radioactive materials in Canada is governed jointly by CNSC and Transport Canada (TC) under several pieces of legislation, including, but not limited to, the Transportation of Dangerous Goods Act (S.C. 1992, c. 34), the Packaging and Transport of Nuclear Substances Regulations (PTNSR) (SOR/2015-145), the Nuclear Safety and Control Act (S.C. 1997, c.9), and the Nuclear Security Regulations (SOR/2000-209).

Under the framework set out by the above-noted legislation, radioactive materials are defined as Class 7 Dangerous Goods and can be further categorized according to their specific properties pertaining to the type and level of ionizing radiation that may be applicable. Thousands of shipments of radioactive materials are safely carried out within Canada annually by various industries, including power production, surveying, and nuclear medicine.

Drawing from the International Atomic Energy Agency’s *Regulations for the Safe Transport of Radioactive Materials* [1], Canada’s PTNSR sets out requirements for the types of packages that must be used to transport various categories of radioactive materials.

This includes the content characteristics and the safety-related performance of packages during normal conditions of transport (NCT) and hypothetical accident conditions (HAC). Different types of packages may be required depending on the nature and form of the content. These include, but are not limited to:

Type IP Packages	Type A Packages	Type B Packages
These packages are utilized for shipping materials considered to pose a low risk or hazard due to the nature and level of the contents (low specific activity or surface contamination). They provide a basic level of protection and shielding and must withstand normal transport conditions, among other requirements.	These packages are designed for the transport of moderately radioactive materials. They provide a higher level of protection compared to Type IP packages. They are rated to contain levels of ionizing radiation below a given threshold value (known as an A₂ value ^{a)}) which varies depending on the nature of the contents.	These packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions.

Type IP Packages	Type A Packages	Type B Packages
Common contents include surface-contaminated clothing or PPE.	Common contents found in Type A packages include radiopharmaceuticals and other industrial materials.	Type B packages are commonly used to transport used nuclear fuel.

^a The A_2 value is the maximum amount of radioactivity of a specific radioisotope measured in terabecquerel (TBq) than can be transported in a Type A package for normal form materials like most radioactive waste. In other words, the amount of radioactivity they contain is limited by regulations and in the event of a release, these limits ensure that the risk from radiation/contamination is managed.

This assessment concerns road and rail conveyances capable of transporting **Type B packages** certified to transport used nuclear fuel.

Safety of Type B Transport Packages for Used Nuclear Fuel

The basic philosophy behind the Canadian transport regulations is that safety heavily relies on the design of the transport package. Used fuel packages, or Type B packages are designed, tested and certified to retain their contents during normal operations and in the event of a credible accident. Under the regulations, the package design has to meet a series of rigorous impact, fire and water immersion tests:

- Two drop tests: 1) a 9 metre drop onto an unyielding surface and; 2) a 1 metre drop onto a steel bar at least 20 centimeters long; conducted in the sequence and orientation that would result in the most damage to the package.
- Following the drop tests, a fire test on the same specimen which the package is subjected to a fully engulfing fire of 800°C for 30 minutes.
- Immersion test where the cask is then subjected to conditions equivalent to 15 metre submersion for 8 hours. For casks designed for the more highly radioactive materials there is an enhanced immersion test of 200 metres for 1 hour.

These tests ensure that packages can withstand accidents involving crashes, fires, or submergence under water that can realistically be envisioned.

2.3.2 Type B Transportation Packages and Conveyances

NWMO is currently assessing several conveyance options for transporting various Type B transport packages from interim storage sites to the APM DGR. Types of conveyances being considered include the:

- Truck tractor (see **Figure 2**)
- Rail consist (see **Figure 3** for an image of the rail consists and **Figure 4** for an image of the 8-axle DSC-TP railcar)
- Heavy haul truck (super-load truck).⁶

Depending on the final mode chosen and the storage method utilized at the interim storage sites, these conveyances may transport various Type B transportation packages (i.e., the Used Fuel Transportation Package, the Dry Storage Container Transportation Package, the Basket Transportation Package).

⁶ Heavy haul truck has been scoped out of this report because there were no databases containing collision information on these types of conveyances, therefore the focus of this report is on truck tractors and rail consists.

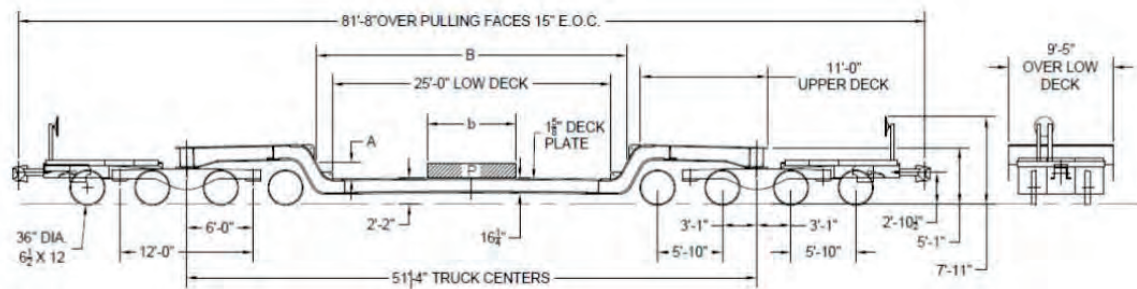
Figure 2: An illustration of Road Conveyance with Used Fuel Transportation Package (top) and Basket Transportation Package (bottom)



Figure 3: An illustration of Dry Storage Container Transportation Packages and Supporting Rail Consist



Figure 4: An illustration of the 8-axle Dry Storage Container Transportation Package Railcar



2.4 Content of the Report

This report encompasses the work completed in Work Packages # I and # II. It focuses on event tree development, transportation collision probabilities, and transport safety.

This report intends to analyze historical collision conditions to quantitatively assess collision probabilities which may apply to road and rail conveyances which are being considered by NWMO for transporting Type B packages.

As noted previously, the consequences or potential impacts (environmental impacts, health effects or injuries) following a collision or breached Type B transportation packages are not considered within the scope of this assessment.

Literature Review	Summarizes a review of the technical and scientific literature used to assist in developing the methodology for the risk assessment component related to the transportation of radioactive materials.
Methodology	Outlines and justifies the chosen approach regarding data collection, the applicability of screening criteria, and the development of event trees to assess collision events for road and rail.
Collision Datasets and General Statistics	Provides an overview of the datasets collected as part of the assessment, their contents, and applicability to the project objectives, along with the measures used to ensure that event trees are based on reliable and comprehensive data. This section also provides highlights of the collision databases for the most relevant geographic study areas.
Collision Types and Attributes	Provides a breakdown of the collected datasets regarding collision categories, attributes, and contributing factors. Emergent trends and themes of interest are briefly described in this section.
Screening Criteria	Discusses the applicability of different screening criteria that could be applied to the chosen datasets to account for contributing factors or conveyance types that further define the available data for creating event trees.
Event Trees	Provides a detailed look at the construction of event trees for road and rail conveyances. The event trees are then presented, and the initial general outcomes of the study are touched on.
Calculation of Collision Scenario Probabilities	Provides a further breakdown of the results showcased in the event trees by looking at the specific probabilities and outcomes of the road and rail collision events.
Sensitivity Assessment	Describes what are considered bounding collision scenarios as well as a discussion of the top-probability collision occurrences and scenarios. Based on these, themes of interest are discussed, and a sensitivity analysis is conducted.
Benchmarking	A benchmarking exercise is carried out against previous probabilistic assessments.

2.5 Assumptions

For this report, the following assumptions apply:

- The scope of work on data collection efforts is limited to collecting and analyzing relevant collision datasets based on the road and rail conveyances proposed to transport NWMO's used fuel shipments and does not include discussions on the quality of the data received from different resources.

It is important to note that various factors can affect the accuracy and completeness of truck and train datasets as applicable to any dataset collected manually.

For example, collision information for road only transportation collected by police officers following an investigation usually undergoes an internal quality review process. However, this process is not guaranteed for all reported collisions.

Some of the most common challenges in road collision data collection and reporting include incomplete data, delays in entering data into databases, and errors/inconsistencies in data entries. In the cases of self-reported collisions, errors and inconsistencies are expected to occur more frequently than in forms completed by police officers.

The project team acknowledges the potential shortcomings in the accuracy and completeness of data and remains unbiased in assessing different resources concerning data quality.

- The timeframe for collision data collection and analysis for truck and train movements was for the years 2010 to 2019 inclusive. Data from 2020 through 2022 were not used because of the transportation-related impacts stemming from the COVID-19 pandemic.

Data for those years is not considered representative due to economic slowdowns and overall commercial and private transportation reductions that occurred during the time period.

- The development of collision event trees and the calculation of probabilities are not route or location specific.
- It is assumed that the individual events are statistically independent. In other words, the occurrence of one event (e.g., a head-on collision) does not affect the probability of the other (e.g., a collision with a bridge structure).
- The scope of work does not involve analyzing consequences in the event of a road or rail incidents.

3 Literature Review

3.1 Transportation Safety Assessments & Statistics within Canada

Two primary references were identified as being directly applicable to the topic of radioactive material transport in the Canadian context:

- “Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Collisions on Canadian Roadways,” as conducted by Lloyd’s Register for the CNSC [2], and
- “A Probabilistic Risk Assessment of Truck/Trailer Transportation of Radioactive Material in Canada,” summarizing the first report for presentation at PATRAM [3].

Each of these documents considers only truck transportation. Similar or parallel studies have not been conducted for train transport in Canada.

The Lloyd’s Register report explored the applicability of probabilistic assessment methods on collisions involving large trucks on Canadian roadways, noting that *“since radioactive material transport collisions are extremely rare, the associated statistics are insufficient as the basis for the collision event tree.”* In turn, analogous collision data, in the form of tractor-trailer collisions involving non-radioactive payloads from 2011 – 2015, was utilized to apply probabilistic assessment methods effectively.

The report concluded that *“sufficiently comprehensive and detailed data exist for the creation and use of event trees specific to collision probabilities on Canadian roadways”* to inform the general public of the relative transport collision risks.

To apply Canadian roadway collision data to conveyances transporting Type B packages, screening criteria were applied to the dataset for conveyance type (unit truck >4536 kg, truck tractor) to exclude such contributing factors as, alcohol, drugs, and disobeying of traffic control, etc., as the latter were identified as *“not applicable to drivers of trucks carrying Type B containers.”* A similar screening approach was considered for this analysis as outlined in **Section 7 Screening Criteria**.

Among the recommended areas for future study were the development of collision event trees for other modes of transport, the development of guidance on how to reduce the probability of collisions that are more likely to result in severe or demolished vehicles, and how to translate vehicle damage severity to Type B package consequences – topics which informed the scope of the current assessment.

Thus, the Canadian literature, while limited, sets the groundwork for the current assessment. It does this by verifying that probabilistic assessment methods involving conventional transportation collisions may be utilized to assess transportation collision scenarios relevant to Type B packages transported along Canadian highways, laying out a viable methodology and screening criteria, and identifying areas where more research is required.

3.2 Transportation Safety Assessments & Statistics within U.S.

Due to the United States' extensive history of radioactive material transport and infrastructure and legislative similarities to the Canadian context, the United States was identified as a source containing several reports of interest.

3.2.1 Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes - 1977 [4]

In 1977, the United States (U.S.) Nuclear Regulatory Commission (USNRC) produced the “*Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*.”

This report (NUREG-1070) focused on gauging the radiological impacts of shipments of radioactive material within, to, and from the United States.

While the report is primarily concerned with calculating the radiological impact across all modes of transport under incident-free and accident conditions, a portion of it is devoted to identifying the probability and consequence (collision rate per vehicle-kilometer) of transportation collisions for each mode.

Furthermore, the report uses a classification scheme accounting for crush force (road), impact force (rail) and fire duration to assign severity categories and fractional occurrence rates to population density zones. As such, this study is not directly applicable to the current report, which focuses on the factors and statistics leading to a road or rail collision instead of the radiological impacts of such hypothetical collisions.

3.2.2 Modal Study – 1987 [5]

To account specifically for severe highway and railway collisions, the USNRC, in collaboration with Lawrence Livermore National Laboratory (LLNL), conducted the “*Shipping Container Response to Severe Highway and Railway Collision Conditions*” report in 1987. This report (NUREG/CR-4829), known as the “Modal Study,” aimed to estimate the adequacy of radiological protection afforded by shipping casks (Type B containers) during highway or rail incidents either within or exceeding regulatory collision conditions.

To screen the collision criteria, collision rates were estimated from historical collision records for truck and train incidents for similar vehicles. Collision data from the Bureau of Motor Carrier Safety was used to identify collision types, build event trees, and identify average collisions/vehicle mile rates. Based on these collision combinations, mechanical and thermal loading scenarios were identified and screened as within or exceeding regulatory collision conditions.

These conditions were then applied to representative spent fuel casks, and the structural and thermal responses were analyzed. The report concluded that based on the screening and assessment of real collision cases and respective collision conditions applied to representative casks, the level of protection afforded by the regulations (U.S. 10 CFR 71) is “adequate and not in need of immediate change.” Thus, the Modal Study assures that such a probabilistic approach can be applied conservatively to gauge collision probabilities relevant to used fuel shipping casks during transport.

3.2.3 Re-examination of Spent Fuel Shipment Risk Estimates - 2000 [6]

A third study (NUREG/CR-6672) was carried out in 2000 titled “*Reexamination of Spent Fuel Shipment Risk Estimates*” by USNRC in collaboration with Sandia National Laboratories, which aimed to reassess the transportation risks identified in NUREG-1070 and NUREG/CR-4829 utilizing finite element analysis (FEA) and heat transport calculations.

The study carried over collision severity fractions from the Modal Study but augmented the data with geographic information next to potential transport routes (i.e., hard vs soft rock surfaces). It concludes that the previous studies “made several very conservative assumptions about [...] cask response to collision conditions, which caused their estimates of collision source terms, collision frequencies, and collision consequences to also be very conservative”.

This study successfully re-utilizes event tree collision data from the Modal Study and applies the outputs to more advanced analytics methods than previously available, once again demonstrating the validity of probabilistic assessment methods’ capability to quantify collision types and likelihoods.

3.2.4 Tractor/Trailer Collision Statistics – 2006 [7]

Sandia National Laboratories published “*Tractor/Trailer Collision Statistics*” in 2006 (SAND2006-7723), in part due to discussions with the public which suggested that the “*Modal Study event tree should be reconstructed using recent truck collision data.*” Recent collision highway data (1996 – 2000) is utilized to construct and contrast a collision event to the Modal Study.

The report notes differences between its event tree data and that of the Modal Study but goes on to state that they “*are not so different as to suggest that the nature of truck collisions has changed drastically during the last two decades*” and that “*the probabilities of severe collisions during the transport of spent nuclear fuel by truck have not been found to be significantly greater than those estimated in the Modal Study.*” The report further solidifies that probabilistic methods, particularly event trees, are useful for assessing collision types for used fuel transportation casks shipped over highways and railways.

3.2.5 Spent Fuel Transportation Risk Assessment – 2014 [8]

A third affirmation of the U.S. regulations came in the form of NUREG-2125, *Spent Fuel Transportation Risk Assessment* (2014), which concluded that, with improved analysis tools, techniques, data availability, and reductions in uncertainty, the “*estimate of collision risk from the release of radioactive material in this study [are] approximately five orders of magnitude less than what was estimated in NUREG-0170*”.

With regards to collision data, it goes on to state that although “*the most applicable frequency would be the frequency of collisions involving vehicles carrying spent nuclear fuel (SNF), [...] there have not been enough collisions worldwide involving spent fuel transportation to provide an adequate statistical database*”, and opts to base its assessment on highway collisions involving large semitrailer trucks and freight rail incidents for conventional conveyances obtained from the Department of Transportation (1991 – 2007), further reinforcing the use of probabilistic methods as appropriate for the current report.

3.2.6 Other U.S. Studies

Several smaller U.S.-based studies were queried as part of the literature review; these include:

- *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* – 2006, Transportation Research Board and National Research Council. [9]

This compendium of the history of SNF and HLW transportation provides overviews of the many aspects of transportation, such as regulations, testing, notable incidents, and safety cases, as well as summaries and discussions of related studies as outlined above. It makes recommendations regarding the need to assess long-duration, fully engulfing fires, among others. These recommendations were then addressed in the USNRC’s NUREG/CR-7209. The work on fire accidents demonstrates that current U.S. regulations and packaging standards provide a high degree of protection to public health and safety against releases of radioactive material in real-world transportation accidents, were such events to involve spent nuclear fuel containers. This report does not delve into probabilistic methods beyond what is outlined in the above-noted studies.

- *Recent Assessments in the U.S. of Type B Packages to Impacts Beyond the Regulatory Package Test Standards* – Ammerman et al., 2007, PATRAM Proceedings. [10]

This report analyses USNRC and Sandia documents outlined above, among others, and concludes that based on the data presented, “*the analyses and testing of packages to beyond regulatory impact standards has shown that the packages have a considerable margin of safety against the release of radioactive material*”, and that this “*reinforces the adequacy of the packaging requirements of the U.S. NRC and International Atomic Energy Agency (IAEA) and the methods currently used to certify that spent fuel casks meet these requirements.*” However, this paper does not relate to probabilistic methods regarding collision event trees.

- *Analysis of Serious Truck Crashes in the United States* – Greenberg et al., 2007, PATRAM Proceedings. [11]

This study analyzed crashes involving trucks carrying hazardous materials in order to develop associations between impact measures (crash severity and outcome) and explanatory variables (crash characteristics that help explain cause and effect). Although not specific to radioactive material transport, it notes that the most common vehicle configuration used for transporting hazardous materials is the tractor/semi-trailer.

Many statistically significant correlations are noted between factors relevant to the current report, such as operator experience, driver error, packaging standards, crash configuration, and infrastructure.

- *A Historical Review of the Safe Transport of Spent Nuclear Fuel* – 2016, U.S. Department of Energy. [12]

This report reviews the history of SNF transportation worldwide, notes the strong safety record of such shipments, and investigates incidents involving HLW and SNF transportation. This is primarily a qualitative assessment of historical data and previously outlined USNRC reports regarding transportation collisions and cask response.

While this is a good highlight of the history of SNF transport, there are few discussions on probabilistic methods other than summaries of reports outlined above.

- *Freight Facts and Figures* – 2017, U.S. Department of Transportation, Bureau of Transportation Statistics. [13]

This report provides quantitative summaries of shipments, contents, infrastructure, and conveyance usage for transportation of all type of goods in recent years and provides a good basis for general road and rail transportation statistics and benchmarking. It does not, however, provide insights into probabilistic methods.

- *A Compendium of Spent Fuel Transportation Package Response Analyses to Severe Fire Collision Scenarios* – 2017, USNRC, NUREG/CR-7209. [14]

This report analyzes notable severe railway and roadway fires' potential impact on transportation packages by recreating the fire collision scenario and applying its parameters to a sample of spent fuel casks. Because this report deals primarily with the outcomes of a collision rather than its causal factors and probability of occurrence during transport, it is not directly applicable to the current report.

3.3 International Transport Safety and Collision Statistics

This literature review also looked at several sources describing transportation safety and collision statistics outside of the U.S. and Canada.

- *Input Data for Quantifying Risks associated with the Transport of Radioactive Material* - 2003, International Atomic Energy Agency. [15]

This technical document was developed as part of a coordinated research project in 2003 by the IAEA in order to provide guidance on assessment techniques and sources involved in assessing transportation collisions. It is primarily based around the INTERTRAN2 Computer Code System, which is concerned with estimating dose rates for both normal and collision conditions of transport.

To do so, it must account for probabilities of collisions and associated severities/outcomes in the form of event trees and conditional probabilities for outlined severity levels. Among the potential sources for data input, this report points to “local, regional, and national transport authorities” for highway and rail collision frequency data.

It goes on to state that “a structured analysis of the type, severity and frequency of transport collisions involving [radioactive material] shipments should address the following issues:

- Collision assessment approaches and related data requirements
- Collision identification
- Collision severity categorization
- Collision event frequency estimation
- Reliability of collision assessment model predictions.”

As further detailed therein, this approach is consistent with the probabilistic safety assessment methods identified in the above-noted U.S.-related literature and the methodology outlined in **Section 4** of this report.

- *Heavy Vehicle Accident Factors* - 2006 - Laboratoire Regional de Lyon. [16]

This 2006 report provided a statistical analysis of heavy goods vehicle (HGV) collisions in France between 1996 and 2001, including breakdowns of collision-prone manoeuvres, road types, profiles and conditions. It did not feature the use of probabilistic methods. Given that analogous comparisons may be possible (i.e., the overall data is sufficiently comparable), this report may be useful for benchmarking against European HGV vehicle collision causes and outcomes.

- *A Review of 10 Years Radioactive Material Transport Incidents and Accidents Experience in Germany* - 2007 PATRAM Proceedings, Gesellschaft fuer Anlagen-und Reaktorsicherheit (GRS). [17]

Event collision data from 1995 – 2006 was compiled and categorized according to type, severity (8 broad safety significance categories), and causal factors. A rudimentary analysis was performed to provide general causes and outcomes of collision events for air, road, and rail shipments, as well as to gauge the effectiveness and adequacy of the regulatory environment. Aside from benchmarking overall radioactive material transport statistics, this study is not relevant to the current report.

- *Evaluation of Safety of French Type B Package Designs in Severe Accident Environments Other Than Regulatory* – 2007 PATRAM Proceedings, French Institute for Radiation Protection and Nuclear Safety. [18]

In this report, cask margins of safety concerning regulatory tests are assessed against real-life collision conditions. Software simulations were carried out on four package models for fires up to 1000°C and falls from up to 40m onto special targets and surfaces of different hardness. While the report concluded that adequate safety margins existed even for greater-than-regulatory test conditions, it ultimately deals with the effects of collisions and not their causal factors during transport. As such, it does not provide relevant input to the current report.

- *Lessons from Transport Events Involving Radioactive Materials Occurred in France Between 1999 and 2009*, 2009 PATRAM Proceedings, French Institute for Radiation Protection and Nuclear Safety. [19]

An overview of collisions and more in-depth analyses of significant events are provided. A rudimentary statistical analysis is performed, highlighting causal factors, including human and organizational factors. The general statistics provided in this report may be used for benchmarking, particularly between package types and respective share of incidents experienced. However, this report has no application of probabilistic methods.

- *Characteristics and causes of heavy goods vehicles and buses accidents in Europe* – 2016, National Technical University of Athens, Austrian Road Safety Board. [20]

This report deals directly with causal factors of HGV and bus/coach collisions. Demographics of HGV and coach/bus collision victims are discussed, particularly in the case of fatalities or serious injuries.

A common methodology is utilized across six (6) major EU nations, including statistical methods aimed to identify non-surface level collision causes specific to HGV and bus/coach operators (i.e., permanent sight obstruction, faulty diagnosis, observation missed, unpredictable system functions/characteristics). While useful for benchmarking, the data utilized in the current report ultimately did not feature the granularity to make one-to-one comparisons for the causal factors listed in the University of Athens' report.

- *Trucks Safety Report - 2017, Volvo. [21]*

This report provides general collision statistics for HGVs across the EU but also utilizes statistical methods to categorize collision causes (human factors, environment, vehicle).

While mainly concerned with reducing fatalities in collisions, the report also provides useful 'typical causes' for collision scenarios such as veering off the road, overturning, frontal collisions, etc., and makes suggestions for improved safety features to abate these scenarios (Advanced Emergency Braking System (AEBS), proximity detection systems, Cooperative Intelligent Traffic Systems (C-ITS)) which would be useful to draw from as part of identifying mitigative factors for collisions.

- *Integrated Risk Assessment Method for Spent Fuel Road Transportation Accident under Complex Environment - 2020, Chinese Institute of Nuclear Energy Safety Technology et al. [22]*

This report utilizes a three-step methodology for assessing collision risks in the form of a comprehensive risk indicator system, event tree modelling, and fault tree analysis of initiating events. It considers road layout, surrounding environment, management, human performance, conveyance specifics and the spent fuel cask. The use of multi-tiered probabilistic risk methods assists in the development of fault conditions upon which a dose assessment is based, further reinforcing the validity of probabilistic risk assessment methods used in the current report.

3.4 Summary

In the reviewed literature, both domestically and abroad, there is significant consensus that the methodology as outlined in **Section 4 Methodology** of this report (that of utilizing general collision statistics involving analogous conveyances to those involved in the transport of Type B packages to develop screening criteria, event trees, and conditional probabilities) is suitable for basing a probabilistic transportation assessment.

Historically, it has been shown suitable for quantifying collision types, the statistical occurrence of those collisions, and their potential impacts on Type B packages during transport. Highly trusted organizations, including national regulatory authorities, have utilized comparable methodologies to accomplish similar goals and have strengthened and reinforced such methods throughout the previous decades.

Regarding data sources, there is consensus among the reports dealing with Type B package transport that due to the historical safety record of such shipments, there is insufficient collision data available to base statistically significant probabilistic assessments.

Rather, collision data pertaining to conventional conveyances, which could be used to transport Type B packages (rail cars, tractor-trailers, and HGVs), should be utilized as input data for the assessment, as a much larger pool of collision data is available to work from. However, it should be acknowledged that additional administrative and technological barriers are applied to Type B shipments that should reduce Type B conveyance collision rates compared to conventional conveyances.

Furthermore, a suitably larger body of knowledge has been developed on tractor-trailer/HGV incidents, collisions, and causal factors from which screening criteria can be identified and conclusions can be drawn regarding the initiating events, exacerbating circumstances and resulting severities of such events.

This pool of knowledge will aid in benchmarking the results of the current report against widely accepted statistics and assist in developing technological or administrative mitigating factors to curtail the probability of collision occurrence or the resulting consequences of such collisions.

4 Methodology

The approach for identifying collision types and calculating respective probabilities is based on comprehensive road and rail event data for the road and rail conveyances which are being considered for use by NWMO to transport used fuel. The information was utilized to develop event trees to demonstrate the possible list of collision scenarios and their resulting probabilities.

The event tree development process is set out in **Sections 4.1** through **Section 4.4** with event trees specifically defined in **Section 4.5**.

4.1 Data Collection

A key report objective was to collect suitable data on which a robust probabilistic assessment may be based. As such, it was determined that ten (10) years of historical collision data pertaining to relevant road and rail conveyances within the geographic study area would prove suitable.

The following relevant sources were identified to support the development of collision even trees:

- Ontario Ministry of Transportation (MTO)
- Québec Ministry of Transportation (MTQ) / Québec Automobile Insurance Company (SAAQ)
- New Brunswick Transportation and Infrastructure
- Transport Canada's Dangerous Good Accident Information System (DGAIS) which contains reports provided at the time of a collision if a release (or anticipated release of the dangerous goods endangers (or could endanger) public safety
- Canadian Nuclear Safety Commission's Event Information and Tracking System (EITS)
- Transportation Safety Board of Canada (TSB)

4.2 Collision Statistics

Following a qualitative and quantitative analysis of the collision data, a breakdown of the percentage of collisions involving conventional shipments by road transport (truck tractor⁷) and rail transport (train) and those involving dangerous goods by type was prepared. **Section 5 Collision Datasets and General Statistics** of the report shows the key highlights of the results of this analysis.

4.3 Screening Criteria

To understand the nature of the collisions that apply to the transport of Type B packages, potential screening criteria were identified through a review of similar assessments (CNSC/Lloyd's Register reports [2] [3]).

Screening criteria refer to certain parameters which may be applied to isolate the relevant portion of the dataset utilized for the probabilistic assessment study.

- For the purpose of this report, the road portion of the analysis focused on datasets of truck tractor collision data as this is the type of conveyance that may be used to transport Type B packages of interest.
- The rail portion of the report did not identify any relevant screening criteria that would warrant application to pare down the dataset to make it more representative of Type B package transportation. Screening criteria are further detailed in **Section 7**.

⁷ On occasion this report uses the word 'truck' as a generic reference to a road transportation vehicle not inclusive of the verbiage 'truck tractor'.

4.4 Collision Events and Causes

The set of collision events was defined by applying the screening criterion to develop the subsequent event trees discussed in **Section 5 Collision Datasets and General Statistics**.

For road transportation, three events can result from an incident as follows:

- 1) A collision with a non-fixed object,
- 2) A collision with a fixed object, or
- 3) A non-collision event.

These three events are consistent with the literature and are considered in this analysis with a fourth “other” event category to account for a small fraction of events with no further information regarding the sequence of events or objects struck.

For rail transportation, the initial events evaluated are derailment and non-derailment events. Contributing factors for actual recorded events are not provided in the collision database. Without such detailed information, the contributing factors for all train collisions could not be identified. However, the event tree was constructed to capture the available data that could represent a cause or consequence of the event.

4.5 Event Trees

In probabilistic analysis, various tools and techniques are useful for mapping out and quantifying events of interest, their initiating factors, and subsequent outcomes. One such technique is event tree modelling, which, historically, has been used within the nuclear industry to identify and assess component or system responses to an initiating event.

A collision event tree describes the progressions of a set of collision scenarios. It is a diagram used to visualize the sequence of separate events or descriptors that form the overall description of the collision scenario when assembled one after each other. An event tree displays a path that starts with the initiating event (trunk of the tree). This then leads to the following event if one occurs (like the branch of a tree), and then to the next event, and so on. Ultimately, this maps out the completely defined collision event scenario in a casual format. When analyzed collectively, the event tree describes the potential outcomes of an initiating event.

Figure 5 shows an example of an event tree for truck movements, developed by *Radioactive Material Transport Probabilistic Risk Assessment - Large Truck Collisions on Canadian Roadways* (“Lloyd Study”) [2].

Figure 5: Example of an Event Tree

Accident	Type	Object struck	Collision configuration	Vehicle damage severity
Large truck accident	Collision with non-fixed object	Train		Demolished
				Severe
				Light/moderate
		Other moving vehicle		Demolished
				Severe
				Light/moderate
		Other non-fixed/moving object		Demolished
				Severe
				Light/moderate
	Collision with fixed object	Bridge	Run-off	Demolished
				Severe
				Light/moderate
			Not run-off	Demolished
				Severe
				Light/moderate
		Other fixed road structure		Demolished
				Severe
				Light/moderate
	Non-collision	Other fixed object		Demolished
				Severe
				Light/moderate
		Ditch		Demolished
				Severe
				Light/moderate
		Embankment, dirt pile, rock		Demolished
				Severe
				Light/moderate
		Fire/explosion		Demolished
				Severe
				Light/moderate
	Other non-collision			Demolished
				Severe
				Light/moderate

This report aims to develop road and rail collision scenario event trees based on real-life road and rail collision data within the relevant Canadian geographical area pertaining to vehicles analogous to those planned to transport used nuclear fuel. The development of these event trees (form and branching pathways) was influenced by previously established event trees for used fuel transportation in Canada and the U.S., as well as the availability of suitable data from which to conduct the assessment.

Based on the application and makeup of event trees seen within the relevant literature (See **Section 4 Methodology**), the primary elements of the event trees were identified and applied. This began with identifying the first branches associated with tractor-trailer and railcar incidents. Consistent with **NUREG/CR-4829, *Shipping Container Response to Severe Highway and Railway Accident Conditions*** (“Modal Study”) [5], they are “collision” or “non-collision” initiating events.

The event trees for road and rail transportation were expanded by subdividing the “collision” and “non-collision” events based on types of objects struck (collisions) and types of non-collision events (e.g., fires, roll-over, etc.), respectively. These subdivisions were commonly seen across the relevant literature and were intended to capture the broadest subcategories of incidents these types of vehicles experience during transportation. Then the type of shipment (i.e., dangerous goods or conventional shipment) and vehicle damage severity were captured in the following branches of the event tree.

For rail transportation, the construction of the event tree was first based on the derailment scenario, as it can be considered a key determinant as to the ultimate severity of the event. This is consistent with event trees created as part of the Modal Study. Next, the event tree was further broken down for different collision types. This included collisions involving track units, fire, explosion, main-track train collisions, etc. The train event tree also included the type of shipment and whether a breach of dangerous goods was noted in the collision, as applicable based on the available data.

The construction of event trees and their branches is tied directly with the selected truck and train movement databases, as discussed in **Section 8 Event Trees** of this report.

The applicable collision data was applied to the individual event tree branches. Where a limiting factor was encountered (lack of sufficient data points, insufficient data parameters, etc.), expert judgement and consultation of the literature for similar challenges was utilized to inform the steps taken. Critical decisions regarding the availability and application of suitable data are discussed in **Section 5 Collision Datasets and General Statistics**.

Within the event tree, the probability of a particular collision scenario is the product of all of the branch point fractions that lie on that scenario path. Therefore, for a total probability in the final column of the event tree, the individual probabilities from each column are multiplied together (moving left to the right). Thus, the branch point fractions must be determined before a particular collision scenario probability can be calculated. The branch point fractions, derived from analysis of the identified data sources, were added following concurrence of the event tree structure.

While the range of types and severity of collisions that could theoretically occur is vast (ranging from minor collisions to incidents with serious outcomes), the analysis does not consider the radiological impact of the collision (e.g., the release of radioactive materials and/or loss of shielding). A full assessment of the potential radiological impacts of a collision entail using models and methods beyond the scope of this assessment.

This report is limited to the probabilistic analysis of incidents and collisions that a conveyance carrying used fuel may reasonably encounter during transport.

4.6 Collision Probabilities

4.6.1 Collision Rate vs Conditional Probability

It is important to note that probabilities calculated using a probabilistic approach are referred to as 'conditional probabilities', which pertain to a particular collision scenario occurring *if* a collision happens.

It differs considerably from 'collision rate', which represents the number of collisions that occur at a given geographic location within a certain timeframe.

In roadway safety studies, traffic volume (measured as million vehicle kilometres) can be used to calculate the collision rate. The collision rate is the number of collisions in a given period (e.g., one year) divided by the traffic volume during the same period.

For example, if 230 collisions occurred in a defined geographic area within one year while vehicles covered 2 million kilometres (km), the collision rate could be expressed as 0.00115 collisions per km or 115 collisions per million km travelled.

Collision rates will vary by geographic region such that one cannot confidently apply a province-wide collision rate to specific routes and expect it to accurately represent the situation on the ground. And such geographically localized data may not be available in sufficient amounts or quality to make use of as part of a sound study.

4.6.2 Conditional Probability of a Scenario

The collision scenario probabilities are calculated and presented without considering collision rates (i.e., collisions per kilometer travelled) or the probability that a truck or train collision happens in the first place.

This report only considers the conditional probability of a collision scenario or the probability of a particular collision scenario occurring *if* a collision happens in the first place.

Therefore, the resulting probability of the exact sequence of collision events defined by an event tree pathway begins with a starting assumption that a collision has occurred.

It has no bearing on the rate of collisions occurring within any specific geographic area timeframe. It pertains only to the probabilistic nature of the specific events following a collision.

4.7 Previous Applications

Collision scenario event trees for road and rail were developed utilizing previously established event tree assessments within Canada and the U.S. for guidance. The literature review presented in **Section 3 Literature Review** identifies methods and assumptions that can be used to inform the development of generic collision event trees and associated collision probabilities related to the transport of Type B packages for relevant road and rail conveyances.

In particular, the Modal Study was one of the first U.S. government guidance documents to explore the use of event trees to examine general transportation collision probabilities and apply them to the transportation of spent nuclear fuel. The Modal Study used the historical train and truck collision data to develop a suite of collision scenarios and associated probabilities displayed as event trees.

Two primary Canadian references provide examples of the use of event trees for evaluating accident probabilities,

- the first being *Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Accidents on Canadian Roadways* [2], as conducted by Lloyd's Register for the Canadian Nuclear Safety Commission (CNSC), and
- the second being *A Probabilistic Risk Assessment of Truck/Trailer Transportation of Radioactive Material in Canada* [3], a summarization of the first report for presentation at the Packaging and Transportation of Radioactive Materials (PATRAM) Symposium in 2019.

This report aims to go beyond the work conducted within these reports by examining the topic of rail transportation. In addition, given that these studies utilized different databases than those used for this report, there exist opportunities to contrast or justify any deviations in the final event trees.

4.8 Applicability to Type B Package Conveyances

Given that the number of road conveyances of spent nuclear fuel in Type B packages is small within Canada, statistical evaluations and probabilities of collisions must be derived from large datasets of collisions involving other heavy vehicles.

In countries such as France, where spent nuclear fuel is transported more regularly due to active fuel reprocessing operations, reasonably sized datasets for spent fuel shipping do exist and they demonstrate that collisions involving these shipments seldom occur. However, it is not appropriate to extrapolate current spent fuel transportation data from Europe to Canada.

To conduct a robust assessment of the possible collision scenarios in Canada, a larger analogous dataset is preferable to a dataset of Type B-carrying conveyance collisions in Canada for which very little data currently exists.

5 Collision Datasets and General Statistics

To ensure that the event tree analysis carried out as part of this report is based on reliable and comprehensive data, it is paramount that sound and reliable data sources are utilized. In anticipation of this work, several federal and provincial organizations within Canada were contacted to identify viable datasets.

Ontario, Québec, and New Brunswick were targeted as provincial data sources of high importance as these provinces store the majority of used fuel to be transported. Of the resulting datasets, variances were identified concerning data attributes required to carry out an event tree assessment of collated datasets.

An overview of each identified dataset, alongside available and missing attributes, collection dates, and usefulness to the assessment, is provided in the following subsections. The collision datasets and general statistics are provided separately for different modes of transportation.

For this report, in consultation with the NWMO, the timeframe for collision data collection and analysis for truck and train movements was increased from five (5) years⁸ to ten (10) years, from 2010 to 2019.

The longer time frame provides an enriched dataset for detailed analysis, aiming to create a better understanding of historical collisions and improve future projection accuracy. It is noted that data from 2020 through 2022 were not used for both road and rail movements because of the impacts stemming from the COVID-19 pandemic. Data for those years is not considered representative due to economic slowdowns and overall commercial and private transportation reductions that occurred during the time period.

5.1 Truck Collision Datasets

Outlined in **Section 2.1 Background**, Canada's plan for the long-term management of used fuel entails transportation from interim storage sites to the DGR location.

Used fuel bundles originate from eight interim storage facilities under the ownership of Ontario Power Generation (OPG) (Pickering, Darlington, and Bruce), Atomic Energy of Canada Ltd. (AECL) or Canadian Nuclear Labs (CNL) (Douglas Point, Chalk River, and Gentilly 1), Hydro-Québec (Gentilly 2), and New Brunswick Power (Point Lepreau), as shown in **Figure 1**.⁹

As such, the following relevant collision statistics in Ontario, Québec, and New Brunswick provinces were reviewed in detail:

- Ontario collision data from the Ministry of Transportation (MTO), from 2010 to 2019, and discussed in detail in **Section 5.1.1 Ontario Collision Data**.
- New Brunswick motor vehicle collision data as reported by the Government of New Brunswick from 2010 to 2019. This database was composed of only motor vehicle collisions involving truck tractors. The details of the New Brunswick database are included in **Section 5.1.2 New Brunswick Collision Data**.
- Québec collision data for the Province of Québec, as reported by the Québec Automobile Insurance Company (SAAQ - Société de l'assurance automobile du Québec) from 2010 to 2019. The details of the Québec database are included in **Section 5.1.3 Québec Collision Data**.

⁸ According to the Highway Safety Manual (HSM), the typical time period examined to assess collision trends when assessing road safety initiatives is five (5) years [23].

⁹ Used fuel from Whiteshell Laboratories (Manitoba) is anticipated to be consolidated at Canadian Nuclear Laboratories (Ontario) prior to the start of NWMO transportation operations.

The following limitations of the collision data sources should be noted when concluding the collision data source:

- Collision data are typically entered manually into the collision database by police officers or individuals involved in a collision, subject to input errors or omissions.
- For self-reported collisions, there may be a bias regarding driver action and condition associated with the at-fault driver.
- For those datasets focused on incidents on provincial highways, the reported collisions will reflect driving characteristics and operating speeds representative of those highways, in contrast to lower-class and municipal roadways.
- Collisions in municipal jurisdictions are excluded from the assessment as no centralized/standardized dataset was identified.

The detailed collision statistics in Ontario, Québec, and New Brunswick include some common data elements. In general, collision attributes in these provinces are reported at two levels:

- **Level #1** - Collision-level attributes, which are those that can be associated with the collision itself, such as impact type, weather condition, and road condition; and
- **Level #2** - Vehicle-level attributes, which are specific for each vehicle involved in a collision, such as a driver condition and driver action.

Table 1 and **Table 2** present the list of collision-level and vehicle-level attributes, their common definitions and availability of information in Ontario, Québec, and New Brunswick datasets, check-marked as “X”.

Table 1: Collision-Level Attributes and Availability of Data

Collision-Level Attributes	Common Definition	Availability of Data		
		Ontario	Québec	New Brunswick
Collision location	Location of the collision in the collision dataset (e.g., intersection, roadway segment, ramp, etc.)	X	X	X
Collision date and time	Date and time of the collision.	X	X	X
Impact type	The impact type describes the general path of the vehicle(s) immediately before the first impact, such as including rear-end, sideswipe, and angle. Detailed information for collision impact type is provided in Section 6.2.1.2 Impact Type.	X	X	X
Collision severity	Collision severity is the quantification of the intensity of an impact, which can result in fatality, injury, or property damage. Detailed information for collision severity data is provided in Section 6.2.1.3 Collision Severity.	X	X	X
Weather condition	The weather conditions at the time of the incident. Detailed information for weather condition is provided in Section 6.2.1.4 Weather Condition.	X	X	X
Road surface condition	The road surface condition at the time of the collision, such as dry, wet, snow, slush, etc. Detailed information for road surface condition is provided in Section 6.2.1.5 Road Surface Condition.	X	X	X
Lighting condition	The type of light that was recorded at the time of the collision, such as daylight, dawn, artificial dawn, dusk, artificial dusk, etc. Detailed information for light condition is provided in Section 6.2.1.6 Lighting Condition.	X	X	X

Table 2: Vehicle-Level Attributes and Availability of Data

Collision-Level Attributes	Common Definition	Availability of Data		
		Ontario	Québec ¹	New Brunswick
A sequence of events	The order of events for each motor vehicle during a collision until it came to rest. Detailed information for sequence of events is provided in Section 6.2.1.1 Sequence of Events	X	X ²	X ³
Vehicle type	Type of vehicle involved in a collision (e.g., passenger cars, vans, trucks, etc.)	X	X	X
Vehicle damage level	Severity of damage for the vehicle involved in a collision (e.g., light damage, moderate damage, severe damage, demolished). Detailed information for vehicle damage level is provided in Section 6.2.1.7 Vehicle Damage Level.	X	-	-
Driver action	The action each driver made immediately before a collision (e.g., driving properly, excessive speed, improper turn, etc.). Detailed information for driver action is provided in Section 6.2.1.8 Driver Action.	X	-	X
Driver condition	The condition of the driver prior to a collision (e.g., impaired, normal, inattentive, etc.). Detailed information for driver condition is provided in Section 6.2.1.9 Driver Condition.	X	-	X
Dangerous goods number (if applicable)	An identifier whether a vehicle involved in a collision was carrying dangerous goods. The breakdown of collisions involving different dangerous goods for the Ontario and New Brunswick is provided in Section 5.1.1.3 Ontario Dangerous Goods Data and Section 5.1.2.3 New Brunswick Dangerous Goods Data.	X	-	X

¹ The Québec database only included vehicle-level attributes for the first vehicle in a collision. The attributes for other vehicles involved in the same collision were not available to the project team.

² The sequence of event attributes in the Québec dataset was only available for the first event of the first vehicle.

³ Initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick.

In addition to detailed collision statistics in Ontario, Québec, and New Brunswick, the collision data collection efforts were extended to the following data sources:

- Dangerous Goods Collision Information System (DGAIS) from Transport Canada (TC) from 2012 to 2021. The details of the DGAIS database are included in **Section 5.1.4 Dangerous Goods Collision Information System**.
- Event Information and Tracking System (EITS) database from the Canadian Nuclear Safety Commission (CNSC), from 2000 to 2022. The details of the EITS database are included in **Section 5.1.5 Canadian Nuclear Safety Commission Data**.

Each of the above data sources are discussed in the following subsections.

5.1.1 Ontario Collision Data

5.1.1.1 Overview of the Ontario Dataset

In selecting a dataset and source most appropriate for the estimation of collision probabilities, it was essential to review the historical collision datasets from the selected provinces.

The MTO maintains a dataset of police-reported and self-reported vehicle collisions on provincial highways. It should be noted that collision data for municipal jurisdictions (i.e., municipally-patrolled highways, including expressways such as the Don Valley Parkway and Gardiner) is not captured within this database and thus is not included as part of this assessment.

As part of this report, detailed collision data for provincial highways in Ontario was acquired from MTO for the years 2010 and 2019 inclusive. The following subsection provides an overview of the general collision statistics.

5.1.1.2 Ontario General Statistics

Table 3 provides a summary of road collisions included in the Ontario provincial database. The breakdown refers to annual collisions for conveyance types which are of interest to this report, including truck tractor and heavy vehicles, as they are similar to those which would transport Type B packages.

- Heavy vehicles include all types of heavy-weight vehicles with similar characteristics in Ontario's database, including truck tractors, open trucks, closed trucks, tank trucks, dump trucks, car carriers, and other trucks (i.e., cement mixers or cranes).
- Truck tractors refers specifically to tractor-trailers. Truck tractor collisions are considered a subset of heavy vehicle collisions.

Section 7 Screening Criteria of the report further discusses the selected vehicle type, ensuring that only relevant categories of conveyances applicable to the assessment are included in the analysis.

As outlined previously, the percentage of collisions involving truck tractors and heavy vehicles is specific to the MTO provincial highways and does not represent the incidents on lower-tier municipalities and regional roads in Ontario.

Table 3: Annual Road Collisions (MTO Ontario Database) by Vehicle Type (2010 to 2019)

Year	Frequency of Collisions (All Vehicles)	Frequency and Percentage of Collisions	
		Involving Truck Tractors*	Involving Heavy Vehicles*
2010	33,245	3,642 (10.9%)	4,960 (14.9%)
2011	36,546	4,047 (11.1%)	5,532 (15.1%)
2012	34,104	3,496 (10.3%)	4,956 (14.5%)
2013	38,982	4,088 (10.5%)	5,667 (14.5%)
2014	38,830	4,376 (11.3%)	6,025 (15.5%)
2015	36,885	3,594 (9.7%)	4,939 (13.4%)
2016	36,049	3,480 (9.7%)	4,833 (13.4%)
2017	36,276	3,709 (10.2%)	5,148 (14.2%)
2018	37,969	3,871 (10.2%)	5,482 (14.4%)
2019	39,202	3,993 (10.2%)	6,071 (15.5%)
Total	368,088	38,296 (10.4%)	53,613 (14.6%)

* The percentages noted in brackets represent the proportion of collisions compared to the total values in the second column.

5.1.1.3 Ontario Dangerous Goods Data

The MTO database includes a field that identifies whether a vehicle involved in a collision was carrying dangerous goods. If positive, the Product Identification Number (PIN) obtained from the placards on the vehicle can also be reported in the database. Confirming whether the PIN was recorded for every collision involving dangerous goods is challenging, and this level of verification was not conducted as part of this report.

Table 4 summarizes the total collisions involving different dangerous goods from 2010 to 2019.

Table 4: Breakdown of Collisions by Dangerous Goods Type (Ontario Database)

Dangerous Goods Class	Dangerous Goods Description	Frequency of Recorded Collisions Involving Dangerous Goods
1	Explosives	2
2	Gases	25
3	Flammable Liquids	47
4	Flammable Solids	1
5	Oxidizing Substances	4
6	Poisonous and Infectious Substances	2
7	Radioactive Materials	1
8	Corrosive Substances	14
9	Miscellaneous Dangerous Substances	0
97	Not Applicable	0
98	Unknown	0
99	Other	2
Total		98

As shown in **Table 4**, less than 0.3% of truck tractor collisions in Ontario provincial highways (98 out of 38,296 truck tractor collisions) involved dangerous goods.

However, as **Section 5.1 Truck Collision Datasets** identified, any attribute included in manually obtained data is subject to omission or input error. The number of collisions involving placarded dangerous goods in provincially patrolled highways in Ontario within the assessed timeframe may differ.

Of those 98 recorded collisions involving dangerous goods, only one incident involved a vehicle carrying Class 7 dangerous goods (radioactive materials). The rarity of such an event is consistent with the findings drawn from the literature review.

The description of this particular event is provided in **Table 8**. In the absence of the total number of dangerous goods shipments in any given year, the frequency of truck collisions involving radioactive materials cannot generate meaningful statistics on the proportion of such incidents in Ontario, and the results should be interpreted with caution.

It is noted that Ontario's database did not provide further details on the type of packages, including Type B transportation packages.

5.1.2 New Brunswick Collision Data

5.1.2.1 Overview of New Brunswick Dataset

New Brunswick motor vehicle collision data from 2010 to 2019, as reported by the Government of New Brunswick, was obtained by project personnel in a spreadsheet format. This database was composed of only motor vehicle collisions involving truck tractors.

In addition, vehicle-level attributes for other types of vehicles involved in a collision with truck tractors were unavailable.

As noted earlier in **Table 2**, initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick.

Due to the lack of vehicle damage level attributes, this dataset could not be carried forward into the event tree stage of the assessment.

5.1.2.2 New Brunswick General Statistics

As noted above, the Government of New Brunswick only provided motor vehicle collisions involving truck tractors. **Table 5** summarizes annual road collisions for truck tractors in New Brunswick's database.

Table 5: Annual Road Collisions in New Brunswick's Database for Truck Tractors

Year	Frequency of Collisions (Truck Tractor)
2010	332
2011	354
2012	282
2013	4 ¹⁰
2014	317
2015	345
2016	282
2017	338
2018	347
2019	371
Total	2,972

5.1.2.3 New Brunswick Dangerous Goods Data

Similar to the data obtained from MTO, the New Brunswick database included a field to identify whether a truck tractor involved in a collision was carrying dangerous goods.

¹⁰ It is noted that the reported truck tractor accidents for 2013 was noticeably less than other years. It is uncertain if the accident dataset is incomplete for 2013.

Table 6 shows collision frequencies from 2010 to 2019 by different dangerous goods classifications.

Table 6: Breakdown of Collisions by Dangerous Goods Class (New Brunswick)

Dangerous Goods Class	Frequency of Recorded Collisions Involving Dangerous Goods
Explosives (Class 1)	-
Gases (Class 2)	6
Flammable Liquids (Class 3)	18
Flammable Solids (Class 4)	1
Oxidizing Substances (Class 4)	-
Poisonous and Infectious Substances (Class 6)	-
Radioactive Materials (Class 7)	-
Corrosive Substances (Class 8)	-
Miscellaneous Dangerous Substances (Class 9)	2
Total	27

Table 6 shows that less than 1% of truck tractor collisions in New Brunswick (27 out of 2,972) involved vehicles carrying dangerous goods.

This is consistent with the collisions involving dangerous goods in the Ontario Dataset. None of the recorded truck tractor collisions involved vehicles carrying Class 7 dangerous goods (radioactive materials).

5.1.3 Québec Collision Data

5.1.3.1 Overview of the Québec Dataset

The detailed collision data for the Province of Québec was acquired from the Québec Automobile Insurance Company (SAAQ - Société de l'assurance automobile du Québec) for the years 2010 to 2019, inclusive. In contrast to the Ontario database for provincial highways, the SAAQ data includes all collisions in the province of Québec on different types of roadways, ranging from local to freeway corridors.

Compared to Ontario's collision database, SAAQ data revealed the following constraints:

- The database only included vehicle-level attributes for the first vehicle in a collision, and the attributes for other vehicles involved in the same collision were not available to the project team. The first vehicle was linked to the first physical event of the collision. The vehicle number for other parties was assigned according to the chronological order in which each vehicle was involved in the collision.
- The sequence of event attributes was only available for the first event of the first vehicle. For example, if a vehicle hit a guard rail (event 1), then ran off-road (event 2), and finally came to rest in a ditch (event 3), only the first event (i.e., hitting a guard rail) was reported in the SAAQ dataset. The information for other events and vehicles could not be provided to the project team.
- Information on collision contributing factors, such as driver action and condition, could not be shared with the project team due to privacy laws in Québec.

5.1.3.2 Québec General Statistics

Based on the available data attributes, the number of road collisions included in the SAAQ database is summarized in **Table 7**. The table also provides a breakdown of annual collisions for relevant conveyance types in the SAAQ database, including a) truck tractors and b) heavy vehicles. Heavy vehicles include all heavy-weight vehicles with similar characteristics in the SAAQ database, including truck tractors and light trucks.

Table 7: Annual Road Collisions in the SAAQ Database for Québec by Vehicle Type (2010 to 2019)

Year	Frequency of Collisions (All Vehicles)	Frequency and Percentage of Collisions	
		Involving Truck Tractors*	Involving Heavy Vehicles*
2010	117,734	4,784 (4.1%)	11,013 (9.4%)
2011	113,127	4,861 (4.3%)	10,512 (9.3%)
2012	104,137	4,442 (4.3%)	9,848 (9.5%)
2013	104,868	4,509 (4.3%)	9,960 (9.5%)
2014	97,686	4,111 (4.2%)	9,320 (9.5%)
2015	98,683	4,134 (4.2%)	9,411 (9.5%)
2016	99,877	4,225 (4.2%)	9,688 (9.7%)
2017	102,698	4,585 (4.5%)	10,608 (10.3%)
2018	100,793	4,721 (4.7%)	11,017 (10.9%)
2019	96,878	4,656 (4.8%)	11,497 (11.9%)
Total	1,036,481	45,028 (4.3%)	102,874 (9.9%)

5.1.3.3 Québec Dangerous Goods Data

In contrast to Ontario and New Brunswick, the SAAQ database did not provide a breakdown of the number or the type of dangerous goods carried by trucks in Québec. As such, no information regarding collision frequencies for truck tractors transporting dangerous goods in Québec is included in this report.

In addition to the above, the percentages of collisions involving truck tractors or heavy vehicles were higher in Ontario's database than in the SAAQ database. This could be attributed to the fact that the MTO database only includes collisions on provincial highways, while the SAAQ database is an all-inclusive database, including collisions on provincial and municipal roadways, with less heavy vehicle and truck tractor traffic on municipal roadways and consequently, fewer collisions.

5.1.4 Dangerous Goods Collision Information System

5.1.4.1 Overview of DGAIS Data

Transport Canada (TC) maintains the Dangerous Goods Collision Information System (DGAIS) to track incidents associated with dangerous goods. DGAIS data was obtained for roads across Canada in a spreadsheet format from 2012 to 2021. This database includes attributes such as incident year, date, time, province, city, location, area, longitude/latitude, initiating event (e.g., loss of control, following too closely, improper loading/unloading/handling), weather condition, presence of spill, leak, fire, or explosion, incident severity (i.e., minor/moderate, major, severe), dangerous goods class and quantities leaked (if any), and incident narrative.

5.1.4.2 DGAIS General Statistics

For the years 2012 to 2021 inclusive, 1,456 incidents involving dangerous goods were reported by Transport Canada. Of these, 302 incidents were recorded for the provinces of Ontario (177), Québec

(113), and New Brunswick (12). It is noted that the numbers reported in the DGAIS data do not necessarily match the provincial numbers discussed in earlier sections.

A variety of reasons can contribute to such discrepancies, such as differences in collision data recording, data accuracy and coding errors; study period (i.e., 2010 to 2019 for the provincial data vs. 2012 to 2021 for the DGAIS data); study area (e.g., provincial highway in the MTO database vs. all type of roadways in the DGAIS data); and the absence of the type of dangerous goods information in the SAAQ database.

Reviewing the incident narrative revealed that the database includes both in-transit collisions and other types of incidents, such as those that occurred during transport and handling. Of those 302 incidents, one event from 2012 to 2021 was related to Class 7 substances (radioactive materials).

Table 8 describes the subject event. This confirms the assumption that the event tree in this report needs to be based on general transport collision data since radioactive transport collisions are rare, and as such, associated statistics are insufficient to form the basis of a robust statistical study.

Table 8: Description of an Incident Related to the Transportation of Class 7 Materials in Ontario

Incident Date	Location	Spill, Leak, Fire, or Explosion	Weather Condition	Incident Narrative
Jan 7, 2018	Highway 17, Sault Ste. Marie	No release / anticipated release	Ice and snow buildup	While carrying radioactive material, the driver of a tractor-trailer, while attempting to go around another tractor-trailer, the side wall caught on the corner of the other truck. The collision is due to winter snowing road conditions. There was no release of radioactive material, injuries, or evacuation, and the highway was closed.

5.1.4.3 DGAIS Dangerous Goods Data

Table 9 further summarizes the total events reported by Transport Canada for the provinces of Ontario, Québec, and New Brunswick involving different dangerous goods classifications.

Table 9: Breakdown of Incidents by Dangerous Goods Class (Transport Canada Database)

Dangerous Goods Class	Province			Total
	Ontario	Québec	New Brunswick	
Explosives (Class 1)	5 (2.8%)	11 (9.7%)	0 (0%)	16 (5.3%)
Gases (Class 2)	54 (30.5%)	31 (27.4%)	6 (50%)	91 (30.1%)
Flammable Liquids (Class 3)	74 (41.8%)	39 (34.5%)	2 (16.7%)	115 (38.1%)
Flammable Solids (Class 4)	0 (0%)	1 (0.9%)	0 (0%)	1 (0.3%)
Oxidizing Substances (Class 5)	9 (5.1%)	6 (5.3%)	0 (0%)	15 (5%)
Poisonous and Infectious Substances (Class 6)	1 (0.6%)	1 (0.9%)	1 (8.3%)	3 (1%)
Radioactive Materials (Class 7)	1 (0.6%)	0 (0%)	0 (0%)	1 (0.3%)
Corrosive Substances (Class 8)	25 (14.1%)	14 (12.4%)	3 (25%)	42 (13.9%)
Miscellaneous Dangerous Substances (Class 9)	5 (2.8%)	2 (1.8%)	0 (0%)	7 (2.3%)
Not Available (blank cell)	3 (1.7%)	8 (7.1%)	0 (0%)	11 (3.6%)
Total	177 (100%)	113 (100%)	12 (100%)	302 (100%)

Table 9 shows that most of the incidents involving dangerous goods in Ontario and Québec were associated with gases (Class 2) and flammable liquids (Class 3), followed by corrosive substances (Class 8).

The only Class 7 incident from 2012 to 2021 was recorded in Ontario, with the incident described in **Table 8**. In New Brunswick, the frequency of incidents involving dangerous goods was noticeably lower than in the other two provinces, with 6 out of 12 incidents labelled as gases (Class 2).

5.1.5 Canadian Nuclear Safety Commission Data

5.1.5.1 Overview of CNSC Data

The Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials to protect public health, safety, security, and the environment. The CNSC maintains an Event Information and Tracking System (EITS) in which accidents, which may or may not be motor vehicle collisions, involving radioactive materials are reported.

In support of the current assessment, the CNSC made available data from EITS covering the years 2000 to 2022 inclusive.

The CNSC database includes but is not limited to the following attributes:

- Date Occurred.
- Event Description, which provides a brief description of the recorded event.
- Packaging Type (e.g., Type B).
- Transport Method (i.e., Road, Rail, Air, Marine, or blank).
- Transport Issue Phase(s) (i.e., During Transport, During Handling, In Transit, or blank). Up to two transport issue phases could be reported for each collision.
- Issue(s) (i.e., Content is Damaged, Improper Packaging, Improper Safety Marks/Labels, Loss of Contents, Signs of Damage, Signs of Tampering, Documentation, Package, Motor Vehicle Accident (MVA), Misrouting, Contaminated, or blank). Up to three issues could be reported for each event.

5.1.5.2 CNSC General Statistics

Between 2000 and 2022, 492 incidents were reported by CNSC, out of which 58 involved Type B transportation packages. Further descriptions of those 58 incidents are provided below:

- A review of the “Event Description” attribute in the CNSC database revealed that approximately 77% of these incidents (45 out of 58) pertained to motor vehicle accidents where the package did not showcase any signs of damage.
- Of the remaining incidents, approximately 21% (12 out of 58) pertained to superficial or minor damage on the surface of the package (i.e., package dropped during handling at an airport).
- There was one recorded instance out of 58 incidents of contamination found on the surface of a package during handling.
- There were found to be no recorded Type B package incidents where a loss of content took place. Similarly, there were no recorded incidents of improper packaging, damaged contents, misrouting, or package loss.

In contrast to the detailed collision datasets in Ontario, Québec, and New Brunswick, the CNSC database did not encompass vehicle type, collision type, sequence of events, contributing factors, vehicle damage severity, an object struck, etc., which are required to create the collision probabilities that are the subject of this report.

Other limitations associated with the CNSC database include a lack of total number of shipments in any given year, the shipment percentage for each package type, and events that may go unreported.

5.2 Train Collision Dataset

5.2.1 Transportation Safety Board Data

5.2.1.1 Overview of TSB Data

In Canada, the Transportation Safety Board of Canada (TSB) has been publishing reportable rail 'collisions' and 'incidents' from its Rail Occurrence Database System (RODS) since 1983. Collisions and incidents, which are called occurrences, were reported in accordance with the TSB Regulations that were in effect at the time of the occurrence.

The TSB database was considered the only source of information about train collisions in Canada that could be utilized to calculate probabilities. The details of the historical occurrences are available on the TSB website [24].

The TSB database includes the following relevant attributes. The options available for each of the attributes are presented in brackets.

- Occurrence number
- Occurrence year
- Occurrence date
- Occurrence type (i.e., collision or incident)
- Occurrence description (i.e., main-track train collision, non-main-track train collisions, passenger, trespasser, employee, crossing, a collision involving track unit, rolling stock collision with an abandoned vehicle, rolling stock collision with an object, rolling stock damaged without derailment/collision, fire, explosion, main-track train derailment, non-main-track train derailment)
- Province
- Subdivision name, mileage and owner
- Type of track (i.e., main, yard, other, or left blank)
- Impact type (i.e., struck by a vehicle, struck vehicle, struck pedestrian, or blank)
- Weather conditions at the time of the occurrence (i.e., freezing rain, hail, rain, snow, or blank)
- Light condition (i.e., dawn, daylight, dusk, night, tunnel, or blank)
- Surface condition (i.e., dry, frozen, snow, wet, or blank)
- Derailment occurrence (i.e., yes, or no)
- Dangerous goods involvement (i.e., yes, or no) and the type of dangerous goods
- Dangerous goods released (i.e., yes, or no)
- Fire (i.e., yes, or no)
- Explosion (i.e., yes, or no)
- Total fatalities, serious injuries, and minor injuries, if any

5.2.1.2 TSB General Statistics

During the time period 2010 – 2019, 11,013 collisions were listed in the TSB database.

Table 10 provides a summary of annual train collisions, including the frequency and percentage of collisions involving dangerous goods. It is noted that the classification of dangerous goods is not reported in this database.

Table 10: Annual Train Collisions in the TSB Database

Year	Frequency of Train Collisions	Frequency of Train Collisions Involving	
		Dangerous Goods*	Released Dangerous Goods
2010	1,160	173 (15%)	3
2011	1,077	123 (11%)	2
2012	1,065	121 (11%)	2
2013	1,112	152 (14%)	17
2014	1,084	163 (15%)	4
2015	1,066	131 (12%)	5
2016	916	104 (11%)	1
2017	1,102	118 (11%)	5
2018	1,174	124 (11%)	2
2019	1,257	169 (13%)	7
Total	11,013	1,378 (13%)	48

* The percentages noted in brackets represent the proportion of collisions compared to the total number of collisions in the second column

While the TSB database indicates that train collisions involving the release of dangerous goods do occur, it was found that the likelihood of such occurrences was less than 0.5% (48 out of 11,013 train collisions). **Section 6.2.2 Train Collisions** of this report further analyzes collision attributes for train movements.

5.3 Summary of Collision Datasets

Section 5 Collision Datasets and General Statistics of this report provided an overview and general statistics of available collision datasets. For truck movement, the Ontario, Québec, and New Brunswick datasets encompassed information on vehicle type, collision type, object struck, etc., which was required to create the collision probabilities that are the subject of this report. As such, the Ontario, Québec, and New Brunswick datasets were carried forward for further analysis and identification of collision attributes; for further detail, refer to **Section 6 Collision Types and Attributes**.

In contrast, the DGAIS and CNSC datasets provided generic collision statistics and did not contain detailed information needed to create event trees.

For train movements, the TSB database was considered to be a comprehensive source of information containing sufficient data for creating the train event tree and calculating collision probabilities.

6 Collision Types and Attributes

The objective of this section is to provide a detailed breakdown of the collision statistics, contributing factors and identify the preferred datasets for the development of event trees and the calculation of the probabilities.

This section is structured as follows:

- **Section 6.1 Categories of Collision Types** summarizes categories of collision types for truck and train movements, including the first set of branches following the initiating event, and provides an overview of the collision attributes in the selected datasets, i.e., Ontario, Québec, and New Brunswick datasets for truck tractors and TSB database for train.
- **Section 6.2 Collision Attributes** presents the selected collision data for truck tractor and train movements, broken down into various categories to better illustrate the nature of incidents within the study period.
- **Section 6.3 Collision Contributing Factors** summarizes the collision contributing factors, which can be utilized to select screening criteria and form the basis of the subsequent probabilistic assessment.
- **Section 6.4 Usability of Collision Datasets** provides justifications for selecting the preferred dataset for identification of screening criteria, development of event trees and the calculation of the probabilities.

6.1 Categories of Collision Types

Following the initial overview of available datasets as outlined in **Section 5 Collision Datasets and General Statistics**, a more thorough breakdown of the collision statistics could be conducted. In anticipation of the formal event tree analysis, this breakdown allows for a better understanding of the collision attributes derived from the datasets. In turn, this allows for the refinement of screening criteria, as applicable, and leads to more concise event tree outputs. This process starts with the identification of collision types for road and rail movements, as discussed below.

6.1.1 Road Categories

A review of the published literature revealed that the first set of branches following the initiating event, such as truck tractor collisions, can be represented by the following four types of collisions:

- Collisions with non-fixed objects (e.g., collision with another moving vehicle);
- Collisions with fixed objects (e.g., impact with hard rock or infrastructure);
- Non-collision incidents (i.e., single-vehicle collision without colliding with any objects, such as run off-road, rollover, fire, explosion, jack-knife); and
- Other events, which is comprised a small proportion of truck tractor collisions with no further information regarding the sequence of events or objects struck.

The above-noted collision types were found to be represented as the “sequence of events” attributes in relevant datasets and discussed in detail in **Section 6.2.1.1 Sequence of Events**.

As noted in **Section 5 Collision Datasets and General Statistics**, the sequence of events was only available for the first event of the first vehicle in the Québec dataset. The absence of such critical information in the Québec dataset would create limitations in utilizing these resources to calculate collision probabilities.

This is further discussed in **Section 6.4 Usability of Collision Datasets** of the report.

In addition to the sequence of events, the information from the selected three datasets from Ontario, Québec, and New Brunswick can be further broken down into the following categories. **Section 6.2 Collision Attributes** summarizes the collision attributes for each of these categories.

- Impact type (**Section 6.2.1.2 Impact Type**)
- Collision severity (**Section 6.2.1.3 Collision Severity**)
- Weather condition (**Section 6.2.1.4 Weather Condition**)
- Road surface condition (**Section 6.2.1.5 Road Surface Condition**)
- Lighting condition (**Section 6.2.1.6 Lighting Condition**)
- Vehicle damage level (**Section 6.2.1.7 Vehicle Damage Level**)
- Driver action (**Section 6.2.1.8 Driver Action**)
- Driver condition (**Section 6.2.1.9 Driver Condition**)

Other categories of interest, such as collisions with bridge structures, run-off roads, or incidents in icy/snow-packed surface conditions that might be an interest to communities and members of the public are discussed in **Section 10.3 Emerging Themes of Interest**.

6.1.2 Rail Categories

For train movements, the published literature divided the first set of event tree branches based on the following two derailment categories [8] [7]:

- Train remains on the rail track; and
- Train derails from the rail track.

It is noted that the above train derailment status can be extracted from the TSB dataset.

In addition to the above-noted collision types, further information was available in the selected datasets for truck and train movements, which assists in creating the collision event trees. This information is discussed in the following sub-sections.

Similar to truck movements, the TSB train database can be further broken down into the following categories:

- Province of occurrence (**Section 6.2.2.1 Province of Occurrence**)
- Derailment scenario (**Section 6.2.2.2 Derailment Scenario**)
- Description of collision (**Section 6.2.2.3 Description of Collision**)
- Collision severity (**Section 6.2.2.4 Collision Severity**)
- Type of shipment (**Section 6.2.2.5 Type of Shipment**)
- Weather condition (**Section 6.2.2.6 Weather Condition**)
- Surface condition (**Section 6.2.2.7 Surface Condition**)
- Light condition (**Section 6.2.2.8 Lighting Condition**)

6.2 Collision Attributes

6.2.1 Truck Collisions

The following sections present the selected collision data in Ontario, Québec, and New Brunswick, broken down into various categories to better illustrate the nature of incidents from 2010 to 2019.

6.2.1.1 Sequence of Events

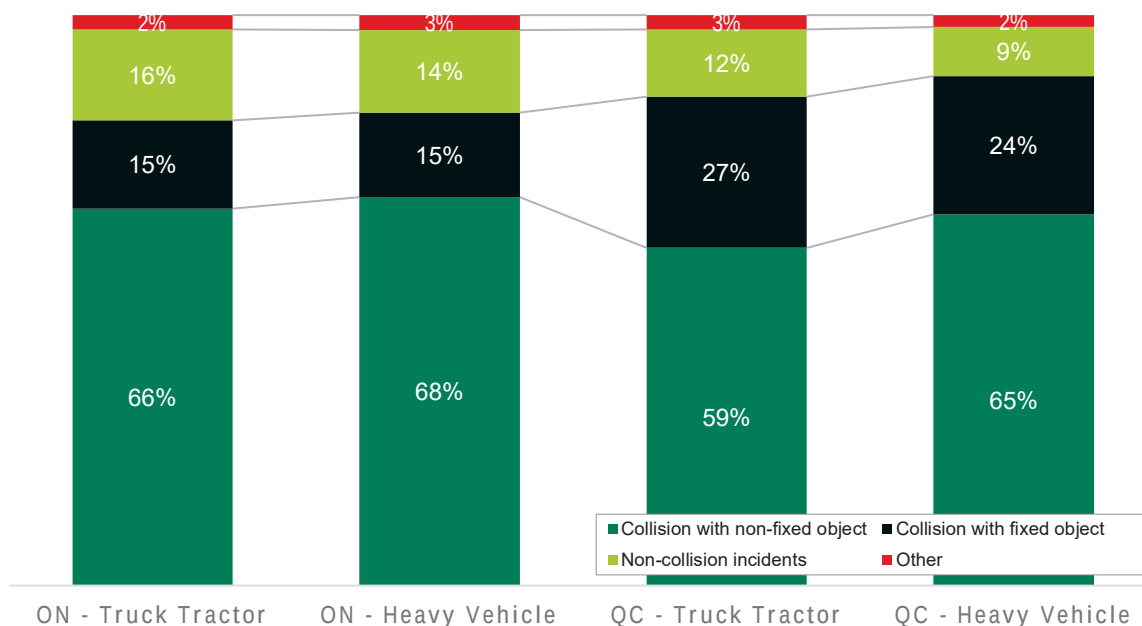
Figure 6 shows the proportion of collisions by the sequence of events, namely collisions with fixed objects, collisions with non-fixed objects, non-collision incidents, and other events. The detailed list of options for each of these collision types is summarized below:

- **Collisions with non-fixed objects:** collision with a train, other motor vehicles, streetcar, farm tractor, other moveable objects, pedestrian, cyclist, animal-domestic, animal-wild.
- **Collisions with fixed objects:** bridge support, building/wall, unattended vehicle, culvert, watercourse, tree/shrub/stump, pole-utility, pole-sign/park meter, submersion, curb, fence/noise barrier, cable guide rail, concrete guide rail, steel guide rail, crash cushion, construction marker, debris on the road, debris off a vehicle, other fixed object, rock face, snow pile, ditch.
- **Non-collision incidents:** fire/explosion, load spill, skidding/sliding, ran off the road, rollover, jack knifing.

The 'other event' category consists of a small proportion of all incidents involving truck tractors for which no further details regarding the sequence of events were provided in the available datasets.

It is noted that initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick. As such, the attributes related to the sequence of events were not reported for New Brunswick.

Figure 6 Proportion of Truck Tractor and Heavy Vehicle Collisions by Sequence of Events



As shown in **Figure 6**, the majority of truck tractor and heavy vehicle incidents were with non-fixed objects, such as another moving vehicle. As noted earlier, the sequence of events for the Québec dataset was only available for the first event of the first vehicle.

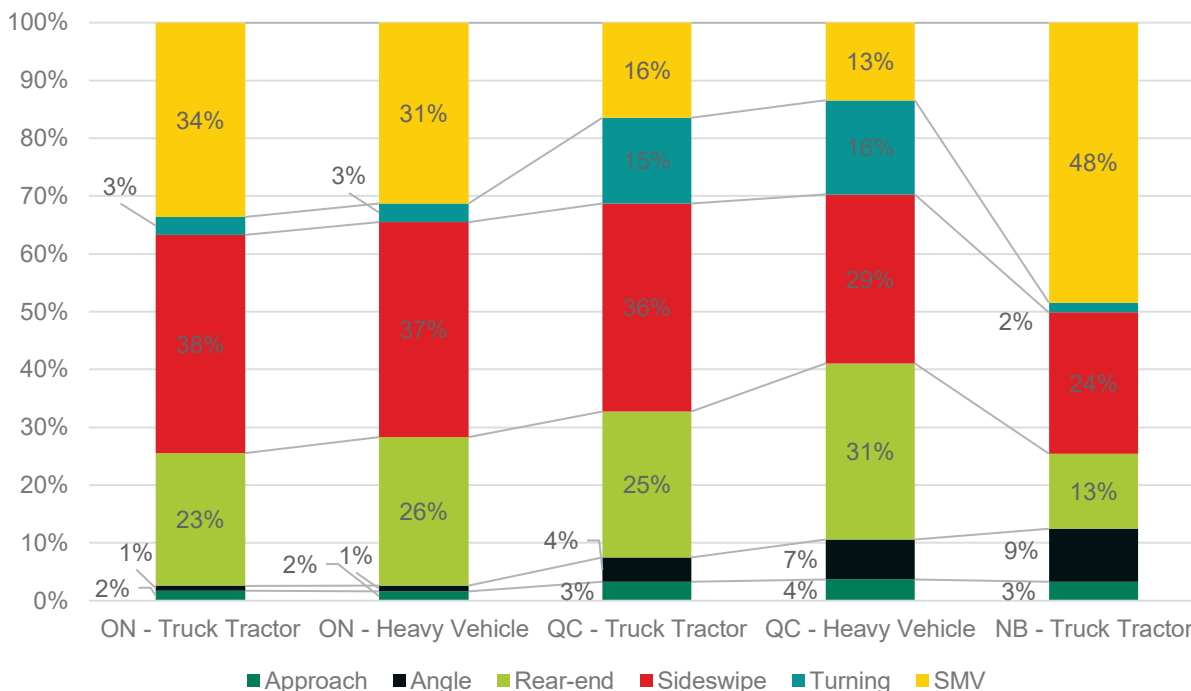
As such, the breakdown of collision data in Québec should be interpreted cautiously.

6.2.1.2 Impact Type

The impact type describes the general path of the vehicle(s) immediately before the first impact, including rear-end, sideswipe, turning, angle, approaching, and Single Motor Vehicle (SMV) collision.

As shown in **Figure 7**, the most common collision impact types for truck tractors and heavy vehicles were sideswipe and SMV, followed by rear-end incidents in all three provinces.

Figure 7: Percentage of Truck Tractor and Heavy Vehicle Collisions by Impact Type

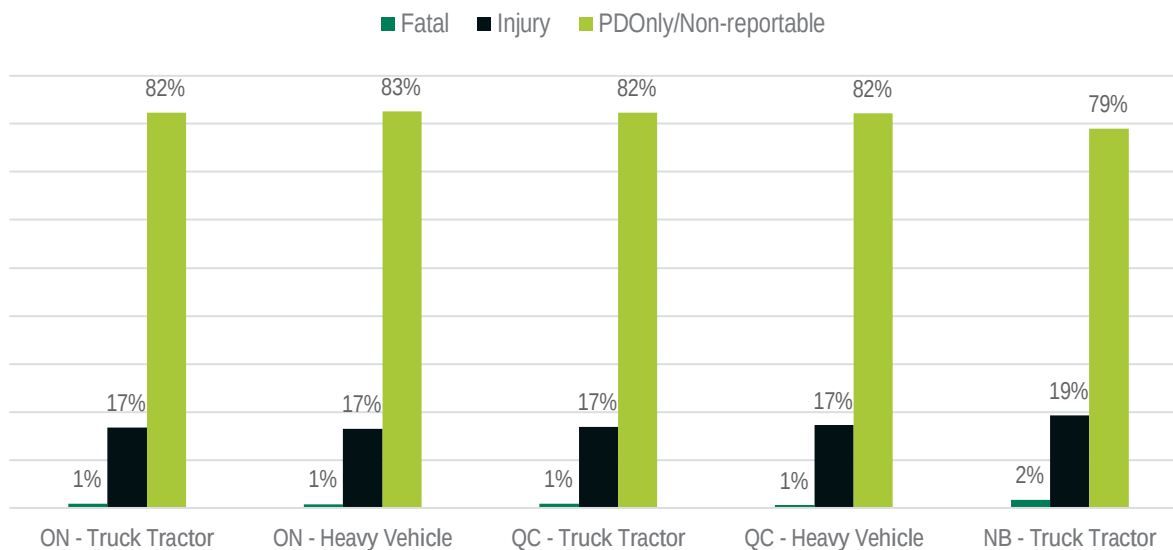


6.2.1.3 Collision Severity

During the study period from 2010 to 2019, 82% of collisions involving truck tractors in Ontario (31,534 out of 38,296 collisions) resulted in Property Damage Only (PDO), approximately 17% (6,405 collisions) resulted in injuries, and less than 1% (357 collisions) resulted in fatalities.

Figure 8 shows that the proportions of collision severities in Québec and New Brunswick were found to be similar to Ontario, with over 79% of collisions resulting in PDO, without any injuries or fatalities. Similar observations were noted for heavy vehicles.

Figure 8: Percentage of Truck Tractor and Heavy Vehicle Collision Severities



6.2.1.4 Weather Condition

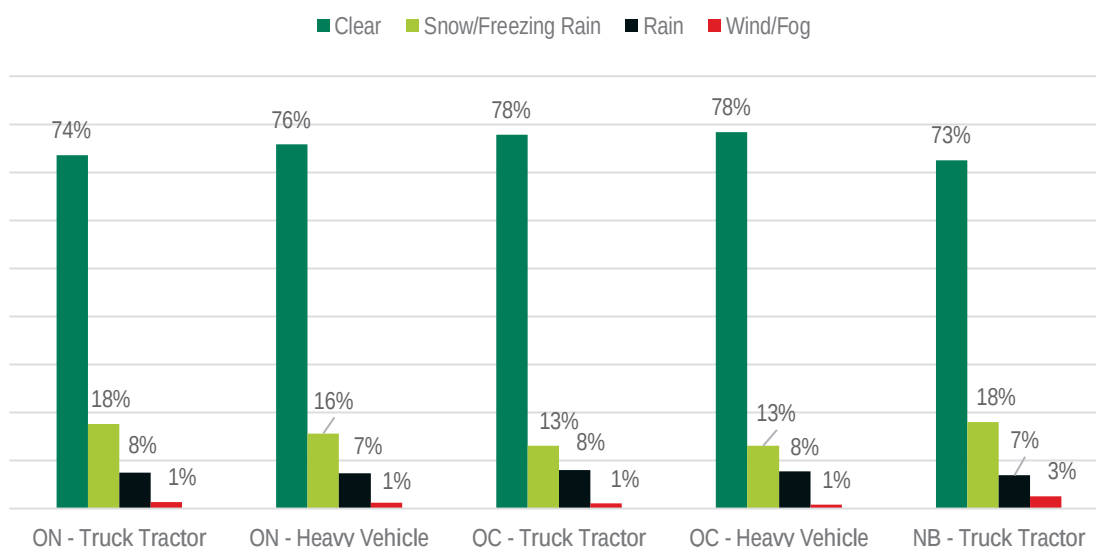
Figure 9 shows the proportion of collisions by weather conditions. For simplicity of reporting, similar weather conditions were grouped as follows:

- Snow, freezing rain, and drifting snow were grouped and labelled as “Snow/Freezing Rain/Drifting Snow.”
- Wind and fog were grouped and labelled as “Wind/Fog.”

Most collisions involving truck tractors and heavy vehicles in different provinces occurred during clear weather conditions.

The proportion of truck tractor collisions during snow/freezing rain was higher in Ontario and New Brunswick (18%) compared to the Québec statistics (13%), while similar percentages across the board were observed for collisions during rainy weather conditions (7% to 8%). Similar observations were noted for incidents involving heavy vehicles.

Figure 9: Percentage of Truck Tractor and Heavy Vehicle Collisions by Weather Condition



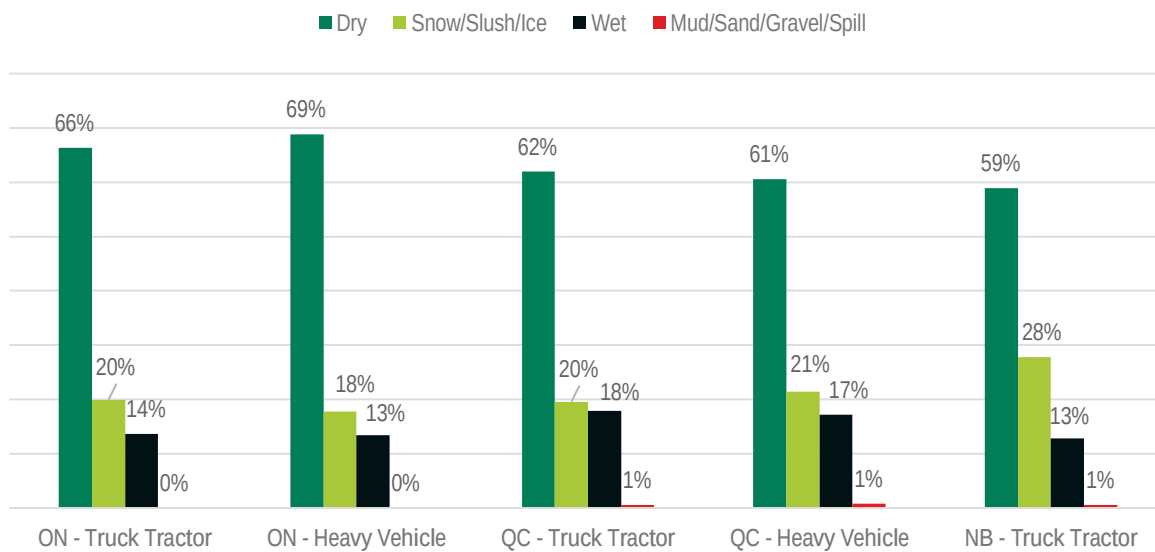
6.2.1.5 Road Surface Condition

Figure 10 shows the proportion of collisions by road surface type. Like weather conditions, similar road surface conditions were grouped as follows:

- Loose snow, slush, packed snow, and ice were grouped and labelled as “Snow/Slush/Ice.”
- Mud, sand/gravel, and spill were grouped and labelled as “Mud/Sand/Gravel/Spill.”

Approximately 20% of collisions involving truck tractors in Ontario and Québec occurred under snow, slush, or ice surface conditions. In New Brunswick, this proportion of collisions in Snow/Slush/Ice was higher compared to Ontario and Québec.

Figure 10: Percentage of Truck Tractor and Heavy Vehicle Collisions by Road Surface Condition



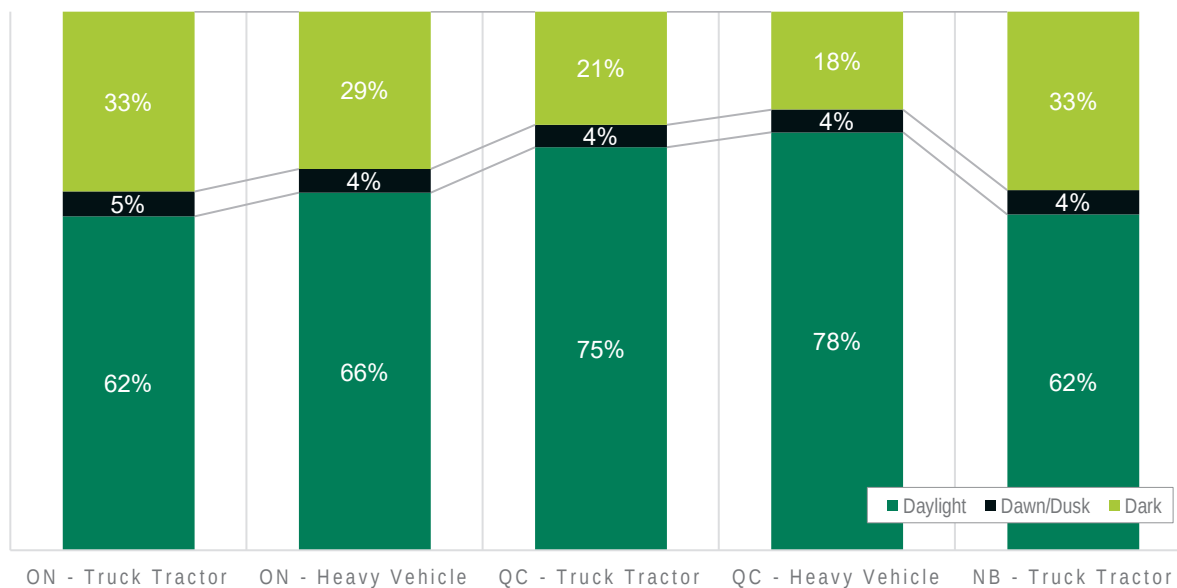
6.2.1.6 Lighting Condition

Figure 11 shows the proportion of collisions by lighting conditions. For simplicity of reporting, similar lighting conditions were grouped as follows:

- Daylight and artificial daylight were grouped and labelled as “Daylight.”
- Dawn, artificial dawn, dust, and artificial dusk were grouped and labelled as “Dawn/Dusk.”
- Dark and artificial dark were grouped and labelled as “Dark.”

The majority of truck tractor and heavy vehicle collisions occurred during daylight. In addition, concerning lighting conditions, the proportion of collisions involving truck tractors followed a similar pattern for Ontario and New Brunswick.

Figure 11: Proportion of Truck Tractor and Heavy Vehicle Collisions by Lighting Condition



6.2.1.7 Vehicle Damage Level

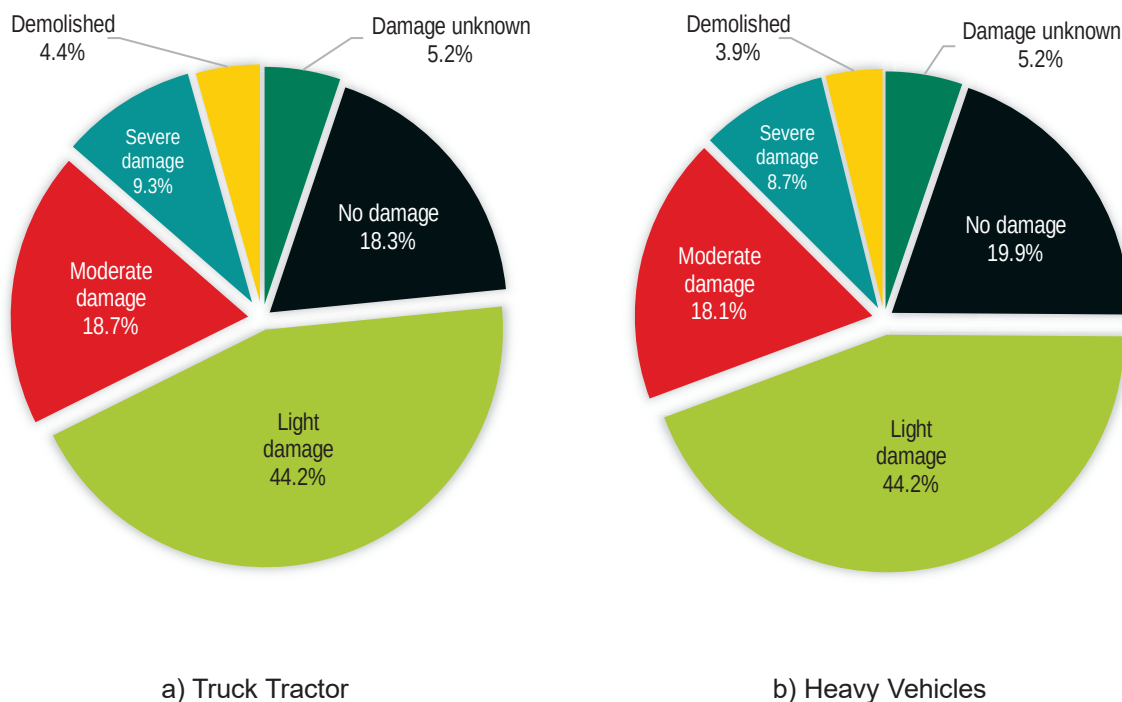
As noted earlier, the vehicle damage level was only available in the MTO's dataset for Ontario. In this database, the vehicle damage level is defined as follows:

- *No damage*: no visible damage to the vehicle involved in a collision.
- *Light damage*: slight or superficial damage. This includes scratches, small dents or minor cracks that do not affect the safety or performance of the vehicle.
- *Moderate damage*: the vehicle must be repaired to make its condition meet the requirements of the law. The vehicle can be driven, but doing so is unsafe.
- *Severe damage*: vehicle cannot be driven and requires towing. The vehicle would normally require repair as a result of the collision.
- *Demolished*: the vehicle was damaged to the extent that repairs would not be feasible.
- *Damage unknown*: this field represents a small proportion of collisions for which the vehicle damage was not recorded.

Figure 12 shows the proportion of truck tractor and heavy vehicle collisions by vehicle damage severity level. As shown in this figure, most collisions resulted in either light damage (44.2%) or no damage (18.3%) to the truck tractor.

It is noted that only 4.4% of truck tractors were demolished as a result of a collision in Ontario's highway network from 2010 to 2019. Similar observations were noted for heavy vehicles.

Figure 12: Proportion of Truck Tractor and Heavy Vehicle Collisions in ON by Vehicle Damage Level

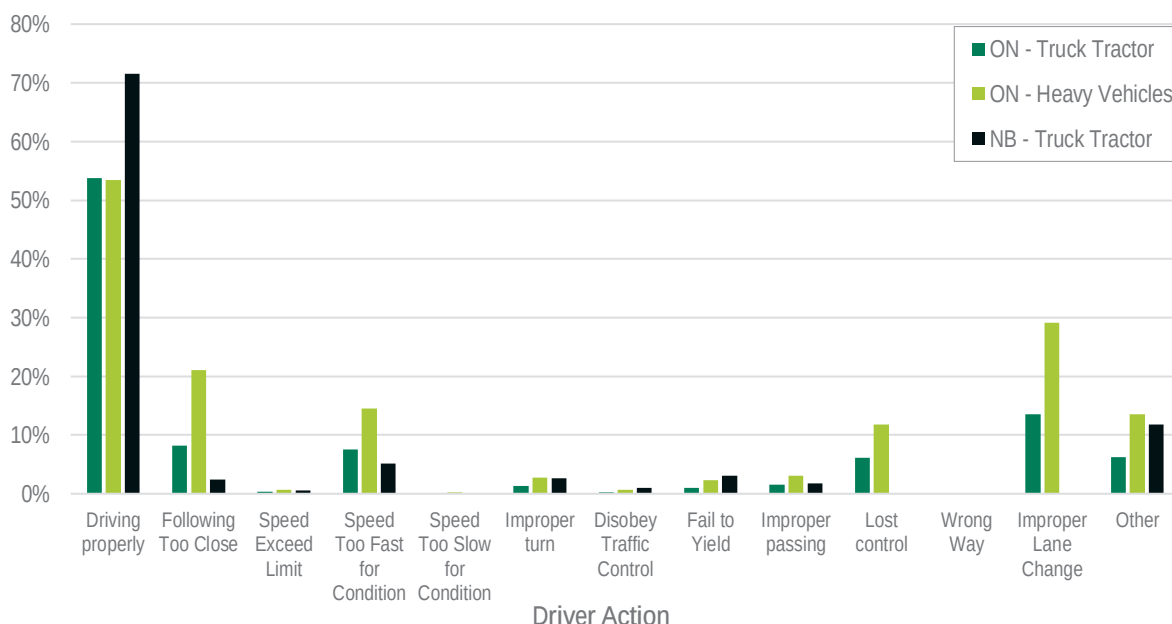


6.2.1.8 Driver Action

Each driver's action immediately before an incident is recorded as driver action in the Ontario and New Brunswick datasets. This information is not available in the Québec dataset due to privacy laws.

As shown in **Figure 13**, the majority of truck tractor and heavy vehicle drivers involved in collisions were driving properly.

Figure 13: Proportion of Truck Tractor and Heavy Vehicle Collisions by Driver Action



Among those drivers that were driving improperly, most of the contributing factors for incidents involving truck tractors in Ontario were improper lane changes (14%), following too closely (8%), and speed too fast for condition (8%).

Similarly, for heavy vehicles, improper lane change (29%) constituted most of the driver actions in improper driving scenarios, followed by following too closely (21%), speed too fast for conditions (14%), and lost control (12%).

It is noted that a fraction of driver actions was coded as 'other' in Ontario (6% for truck tractor and 14% for heavy vehicles) and New Brunswick (12%), with no further details provided in the datasets.

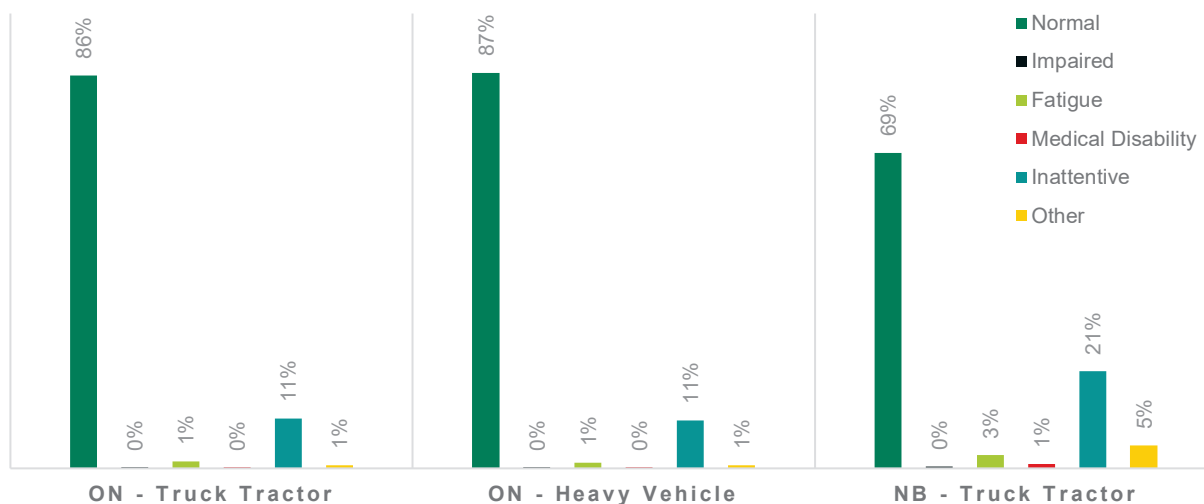
6.2.1.9 Driver Condition

Like driver action, the driver condition attribute was available in the Ontario and New Brunswick datasets, but not available in Québec dataset due to privacy laws.

For simplicity of reporting, similar driver conditions were grouped as follows:

- 'Ability Impaired, Alcohol (over 0.08)',
- 'Ability Impaired, Alcohol,'
- 'Had Been Drinking' and 'Ability Impaired, Drugs' were grouped together and labelled as "Impaired."

Figure 14: Proportion of Truck Tractor and Heavy Vehicle Collisions by Driver Condition



As expected, the driver condition of the majority of truck tractor drivers before the incident was coded as 'normal' (approximately 86% in Ontario and 69% in New Brunswick) shown in **Figure 14**.

As noted, driver inattentiveness was a major contributing factor for incidents involving truck tractors in Ontario (11% of drivers) and New Brunswick (21%). Other factors include fatigue (1% in Ontario and 3% in New Brunswick). Similar observations were noted for heavy vehicles.

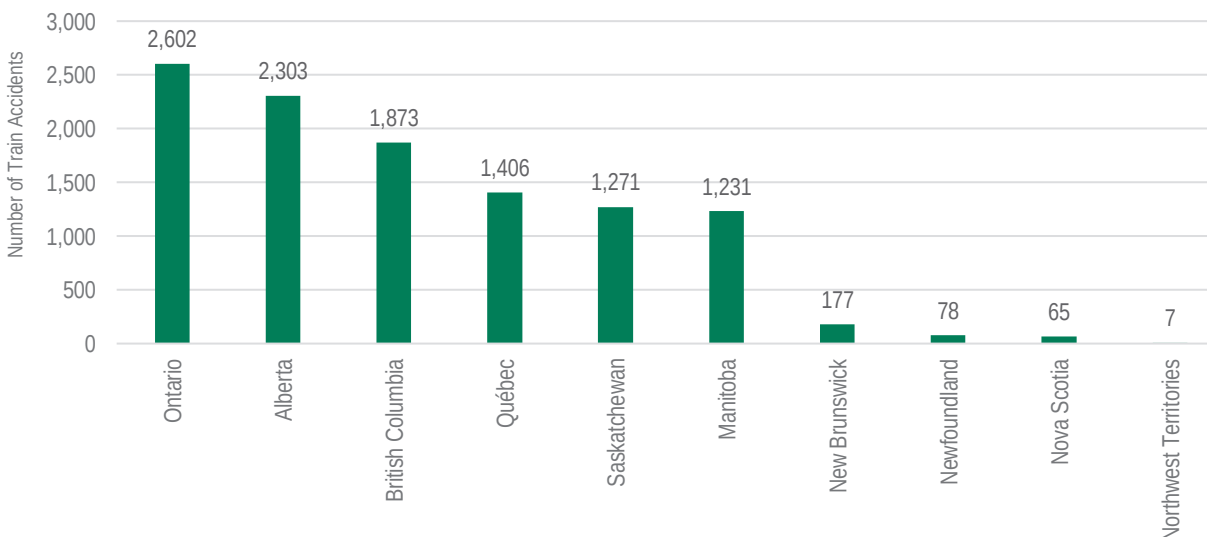
It is noted that a fraction of driver actions was coded as 'other' in Ontario (1%) and New Brunswick (5%) with no further details provided in the datasets.

6.2.2 Train Collisions

6.2.2.1 Province of Occurrence

Figure 15 shows the frequency of train incidents in different provinces and territories in Canada. As shown in this figure, the majority of train collisions occurred in Ontario (24%), followed by Alberta (21%) and British Columbia (17%).

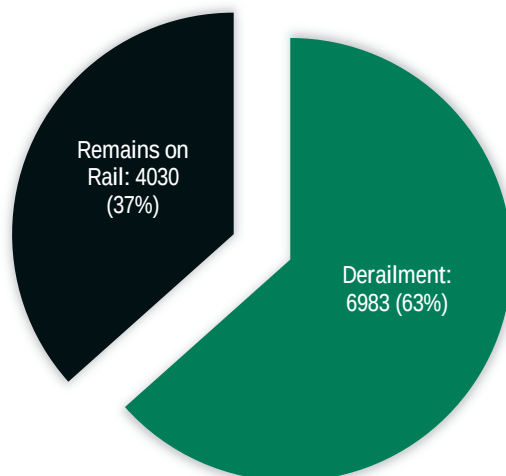
Figure 15: Frequency of Train Collisions in Canada



6.2.2.2 Derailment Scenario

According to the TSB's data dictionary, derailment is defined as any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to the track or equipment. As shown in **Figure 16**, most of the train collisions involved derailments (63%).

Figure 16: Proportion of Train Collisions by Derailment Scenario



6.2.2.3 Description of Collision

The description of the collision is one of the main attributes of the TSB database and includes a variety of information, ranging from the location of the incident (such as a railway crossing), to the object struck (such as a rolling stock collision with an abandoned vehicle).

The first set of branches were aligned to the derailment scenario discussed above, and information in the description of the collision attribute was used to create a second set of branches. As such, separate figures (**Figure 17** and **Figure 18**) were created to illustrate the frequency and percentage of collisions under each derailment scenario.

Figure 17: Frequency and Proportion of Train Collisions (Description - Derailment Scenario)

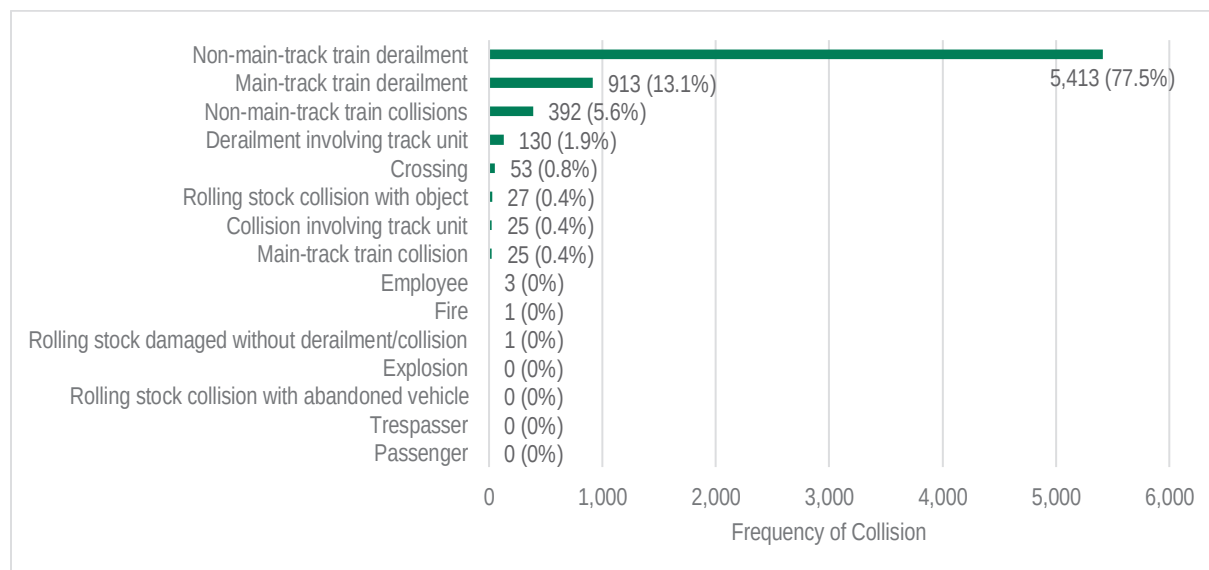
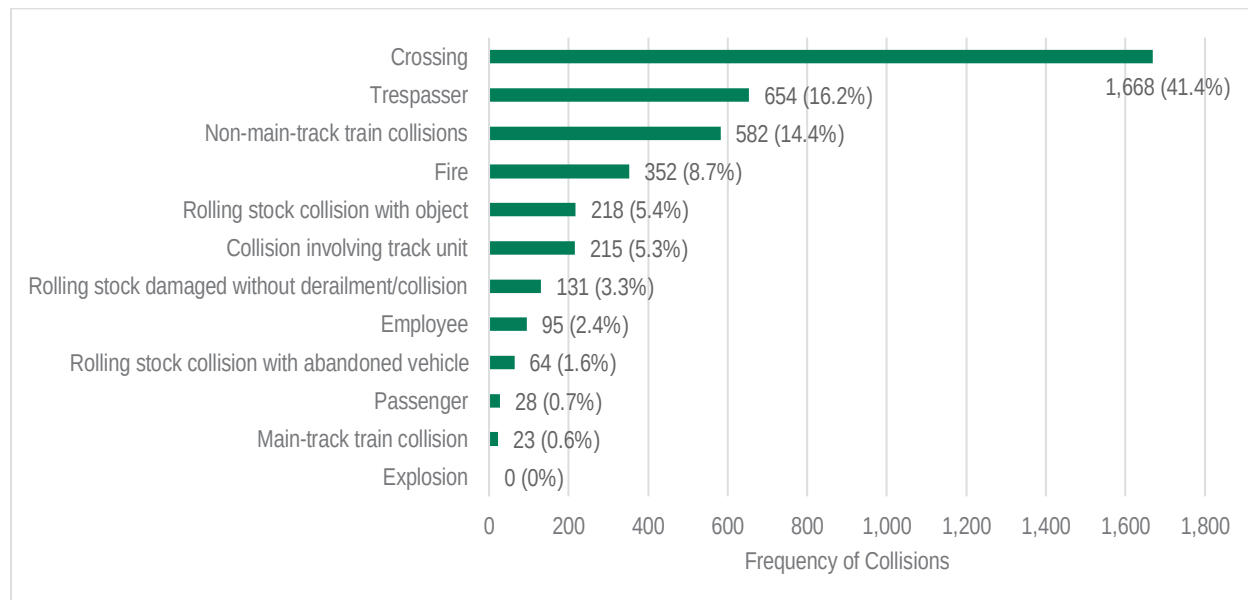


Figure 18: Frequency and Proportion of Train Collisions (Description - Remain on Track Scenario)

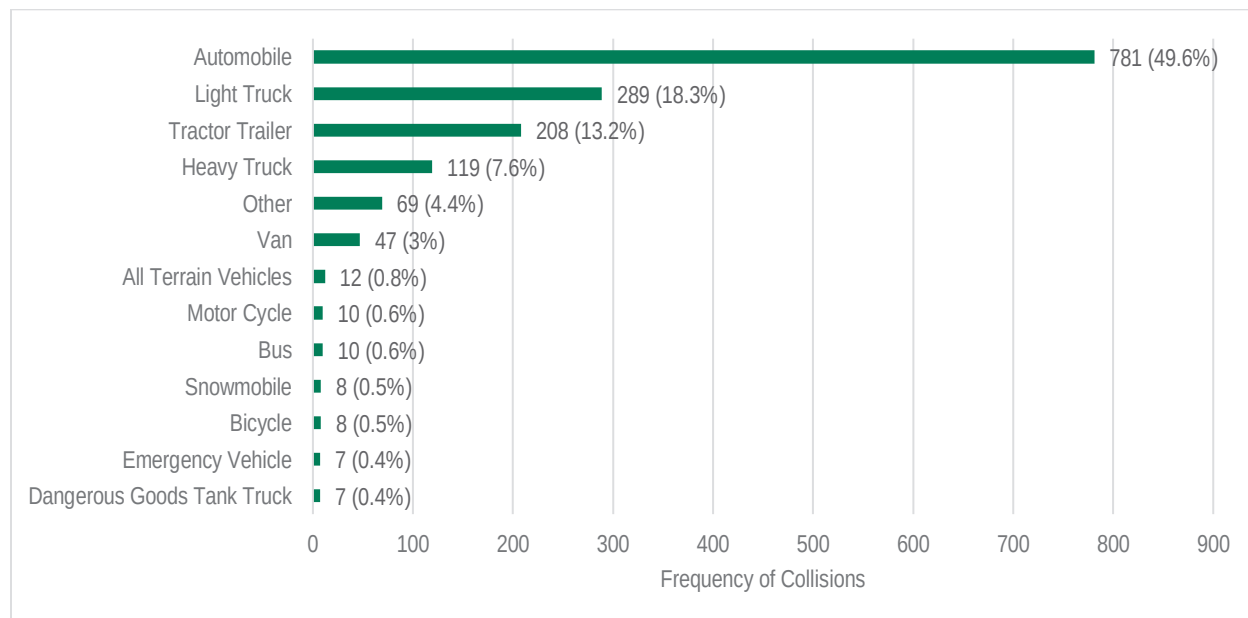


For the derailment scenario, more than 77% of collisions were coded as “non-main track train derailment”, followed by “main-track train derailment” and “non-main-track train collision”.

As shown in **Figure 18**, incidents at railway grade crossings were the most frequent description of collisions reported in the TSB database for those scenarios when the train remained on the railway track. Out of 1,668 incidents at the crossing, the train collided with a vehicle for 1,522 instances, representing more than 91% of collisions at grade crossings. The train struck a pedestrian at a crossing for the remaining 146 incidents (8.8%).

Figure 19 shows that out of 1,575 train collisions with another vehicle at railway crossings, in most cases, the train collided with a passenger vehicle (49.6%), followed by light trucks (18.3%) and tractor-trailers (referred to herein as truck tractors) (13.2%). For 1,522 out of 1,575 train collisions with another vehicle at railway crossings, the train remained on track, while the remaining 53 incidents resulted in train derailment. See **Figure 17**.

Figure 19: Frequency and Proportion of Train Collisions at Crossings by Vehicle Type

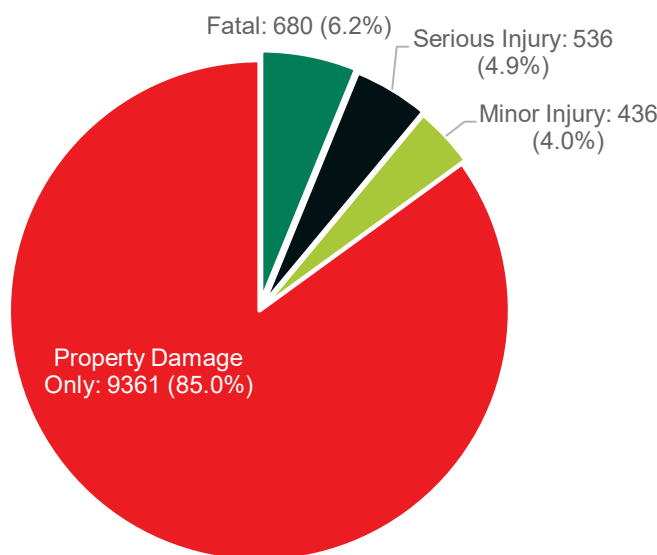


Specifically, for the 208 train collisions with tractor trailers (referred herein as truck tractors) at railway crossings, most of incidents occurred in Alberta (72 collisions or approximately 35%) followed by Saskatchewan (52 collisions or 25%), and only 26 (13%), 19 (9%), and 4 (2%) of incidents occurred in Québec, Ontario, and New Brunswick, respectively.

6.2.2.4 Collision Severity

During the study period from 2010 to 2019, 85% of train collisions (9,361 out of 11,013 collisions) resulted in property damage only and did not result in any fatalities or injuries. **Figure 20** shows a total of 680 fatal collisions during the study period, representing approximately 6% of train collisions. Serious injury collisions accounted for approximately 5% of collisions, followed by 4% of minor injury incidents.

Figure 20: Frequency and Proportion of Train Collisions by Collision Severity



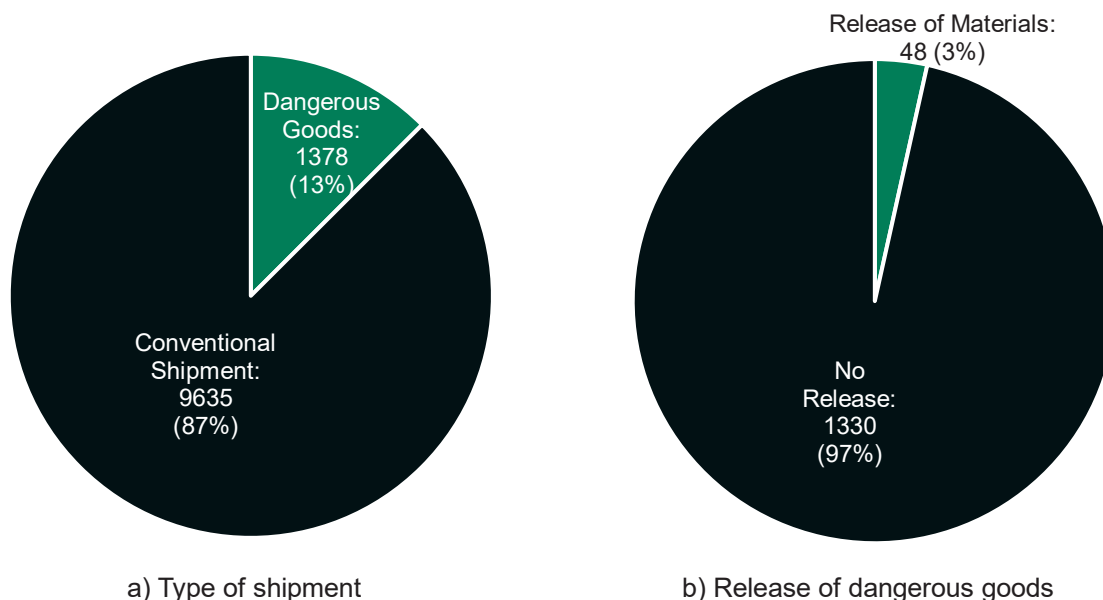
6.2.2.5 Type of Shipment

The TSB database includes a field to indicate whether a train collision included car(s) carrying dangerous goods materials and whether the incident resulted in releasing such materials.

However, the type of dangerous goods, including whether the train incident involved radioactive materials, is not specified in the TSB dataset.

Figure 21a shows 1,378 out of 11,013 train collisions, or approximately 13% of total collisions, involved trains carrying dangerous goods. Out of those 1,378 collisions, 48 (less than 4%) collisions resulted in the release of dangerous goods, as shown in **Figure 21b**. It is noted that no further breakdown of the type of dangerous goods involved in these collisions was available in the TSB database.

Figure 21: Proportion of Train Collisions Involving Dangerous Goods and Release of Materials



6.2.2.6 Weather Condition

In contrast to road vehicle data from the Ontario dataset, the detailed weather condition attributes were only reported for less than 2% of train collisions across Canada. As such, any observations from the available weather conditions would be inconclusive.

Out of 194 incidents with reported weather conditions, 107 or 55% of train collisions occurred during 'snow'. This was followed by 'rain' (74 out of 194 or 38%), 'freezing rain' (11 out of 194 or 6%), and 'hail' (2 out of 194 or 1%).

6.2.2.7 Surface Condition

Like weather conditions, the information on the surface condition was only available for less than 1% of train collisions. Out of 97 incidents with available data, 37 or 38% of train collisions occurred during 'dry' surface, followed by 'frozen' (21 out of 97, or 22%), 'wet' (21 out of 97, or 22%), and 'snow' (18 out of 97, or 19%).

In the absence of a complete dataset, the collision attributes for the surface condition should be interpreted with caution.

6.2.2.8 Lighting Condition

Lighting condition was reported for 896 incidents, representing approximately 8% of total train collisions from 2010 to 2019. The majority of train collisions occurred during 'day' (489 out of 896, or 54%).

Incidents at 'night' followed this (343 out of 896, or 38%), 'dusk' (50 out of 896, or 6%), and 'dawn' (14 out of 896, or 2%).

6.3 Collision Contributing Factors

6.3.1 Truck Collisions

This section summarizes the collision contributing factors discussed in **Section 6.2.1 Truck Collisions**, which can be utilized to select screening criteria and form the basis of the subsequent probabilistic assessment.

Table 11 lists truck tractors' contributing factors derived from the Ontario, Québec, and New Brunswick datasets. The percentages noted in brackets represent the proportion of collisions compared to the total number of truck tractor collisions within each province.

Overall, when comparing the percentages between Ontario and New Brunswick, similar trends in driver actions and driver conditions were observed for most of the contributing factors. It is noted that the weather and road surface conditions were labelled as potential factors, as these conditions may or may not have contributed to a subject incident.

Table 11: Summary of Collision Contributing Factors (Truck Tractor)

Category of Contributing Factor	Contributing Factors	Frequency and Percentage of Occurrence ¹¹ (2010 to 2019)		
		Ontario	New Brunswick	Québec
Driver Action	Following Too Close	3,318 (8.2%)	63 (2.4%)	The information on the driver's actions and conditions could not be shared with the project team, due to privacy laws in Québec
	Speed Exceed Limit	145 (0.4%)	16 (0.6%)	
	Speed Too Fast for Condition	3,048 (7.6%)	136 (5.1%)	
	Speed Too Slow for Condition	52 (0.1%)	0	
	Improper turn	522 (1.3%)	71 (2.7%)	
	Disobeying Traffic Control Devices	104 (0.3%)	25 (0.9%)	
	Fail to Yield	393 (1.0%)	80 (3.0%)	
	Improper passing	620 (1.5%)	48 (1.8%)	
	Lost control	2,447 (6.1%)	0	
	Wrong Way	25 (0.1%)	1 (0.04%)	
	Improper Lane Change	5,448 (13.5%)	0	
Driver Condition	Impaired	112 (0.3%)	11 (0.4%)	
	Fatigue	572 (1.5%)	79 (2.9%)	
	Medical Disability	84 (0.2%)	26 (1.0%)	
	Inattentive	4,167 (10.9%)	584 (21.4%)	
Weather Condition (Potential Factor)	Snow/Freezing Rain	6,724 (17.6%)	530 (18.0%)	5,904 (13.1%)
Road Surface Condition (Potential Factor)	Snow/Slush/Ice	7,615 (19.9%)	821 (27.7%)	8,751 (19.6%)

¹¹ The values presented in the table only represent a subset of the total dataset which exclude some factors that are not likely to contribute to the collisions (e.g., Driver Action of "Driving Properly", Driver Condition of "Normal", Weather Condition of "Clear", and Road Surface Condition of "Dry"). Therefore, the percentages do not sum up to 100%.

6.3.2 Train Collisions

The train operators' actions and conditions were not recorded in the TSB dataset for train collisions. In addition, and as stated in **Section 6.2.2 Train Collisions**, environmental conditions, including weather, surface, and lighting conditions, were only available for a small fraction of train collisions in Canada. In the absence of such detailed information, the contributing factors for train collisions could not be identified.

6.4 Usability of Collision Datasets

6.4.1 Truck Database

Section 6 Collision Types and Attributes of the report provided the collision data analysis findings, aiming to better understand the collision attributes derived from each of the available datasets. A detailed review of the attributes revealed the strengths and shortcomings of the Ontario, Québec, and New Brunswick datasets, as summarized in **Table 12**.

Table 12: Summary of Available Information from Ontario, Québec, and New Brunswick Datasets

Collision Attribute	Ontario	Québec	New Brunswick
Vehicle Involved	All vehicles	Vehicle 1 only ¹²	Truck tractor only ¹³
Vehicle Type	All vehicles	All vehicles	Truck tractor only
Sequence of Events	Up to three events are reported for each incident	The sequence of events was only available for the first event of the first vehicle.	Truck tractor only
Vehicle Damage Level	All vehicles	-	-
Driver Action	All drivers	-	Truck tractor only
Driver Condition	All drivers	-	Truck tractor only
Type of Shipment	Available	-	Available

- Not Available

As shown in **Table 12**, some of the essential collision attributes that are key in assessing screening criteria and developing event trees are not available in the Québec and New Brunswick datasets. For example, the sequence of all events would be needed to create the first branches following an incident.

This information was only partially provided in the Québec dataset for the first event of only one of the vehicles involved in a collision, which may or may not include a truck tractor that was part of the subject collision. As such, the statistics and probabilities generated from the Québec dataset would be largely skewed due to incomplete information.

Similar observations were made for the vehicle damage severity level, which was only available in Ontario's database. The type of shipment was found to be one of the essential elements included as part of the event trees, noted in the literature. Such information was not available in the Québec dataset. Other limitations include information on driver action and condition in the Québec database, which is critical in assessing screening criteria, discussed in **Section 7 Screening Criteria**.

The New Brunswick database only reported collisions attributes for the truck tractor vehicles involved in a collision and did not include the vehicle damage level due to the method through which this attribute is estimated.

¹² The Québec database only included vehicle-level attributes for the first vehicle in an accident, and the attributes for other vehicles involved in the same accident were not available.

¹³ The New Brunswick data only included the collision attributes for the truck tractor vehicles involved in a collision.

Based on the above assessment and considering the limitations of the Québec and New Brunswick datasets, it became evident that the Ontario dataset was the most comprehensive, with sufficient information required for detailed assessment. As such, only the Ontario dataset was carried forward to the next step of the project, including the selection of screening criteria, development of event trees, and calculation of the probabilities, as outlined in the later sections of the report.

6.4.2 Train Database

As for train transport, the TSB database was the only source of information about train collisions in Canada, with available collision attributes like the ones in the literature that can be utilized to develop event trees and calculate collision probabilities.

7 Screening Criteria

It was identified during the literature review stage that certain studies opted to apply screening criteria to their respective datasets to exclude collisions with certain characteristics to more accurately represent the desired data at the event tree analysis stage.

In this context, screening criteria may be considered any significant attribute applicable to a subset of the total data that would warrant inclusion or removal from the subsequent analysis stages.

This section details the process of identifying and justifying selective screening criteria (as seen in the literature or as developed from expert judgement and collaborative discussions) considered relevant and appropriate for the current topic of study.

Furthermore, the calculation of the baseline frequency for contributing factors to be eliminated from the assessment is outlined, and the final screening criteria being carried forward are presented.

7.1 Truck Screening Criteria

On reviewing the Ontario data, an effort was made to review the applicability of various collision attributes to the transportation of Type B packages and “screen” the long list of attributes in Ontario. The following screening criteria were then developed based on the information provided in the literature [2] and previous experience in probabilistic assessment studies:

7.1.1 Conveyance Used

The vehicle classification in this category ranges from heavy transport vehicles and farm vehicles to motorcycles and bicycles. From the long list of vehicle classifications, the following two categories were deemed applicable to this report:

- *Heavy vehicles* include all types of heavy-weight vehicles with similar characteristics. These include truck tractors, open trucks, closed trucks, tank trucks, dump trucks, car carriers, and other trucks (types of heavy trucks, including cement mixers or cranes).
- *Truck tractors* include tractor trailers, with or without a semi trailer. The truck tractors would represent the vehicle type that can transport road-going Type B packages. Truck tractors are a subset of heavy vehicles.

7.1.2 Disobeying Traffic Control Devices

While driver errors can lead to collisions during radioactive material transport, some of the contributing factors listed in **Table 11** may not apply to truck drivers employed to transport Type B packages.

Literature [2] [3] suggests that disobeying traffic control devices can be classified as one of the screening criteria (i.e., some studies have excluded collisions in which the driver’s condition was recorded as “disobeying traffic control devices”) given that truck drivers transporting Type B packages are subject to much more rigorous training requirements.

Applying the same logic, some other driver actions noted in **Table 11** can also be among the candidate screening criteria, such as driving the “Wrong Way.” However, without precedence or evidence from the literature, such contributing factors were not considered screening criteria.

In other words, collisions in which the driver’s condition was recorded as “disobeying traffic control devices” were included in the database and data was carried forward to create event trees and in calculating collision probabilities.

7.1.3 Impaired Driving

It is assumed that drivers of trucks transporting Type B packages are to be held to higher standards than other truck drivers, with extensive training and fitness for duty requirements for operating the vehicle.

This will ensure that such drivers are not operating the vehicle under the influence of drugs or alcohol. Other attributes of driver condition in **Table 11**, such as “Fatigue,” “Medical Disability,” and “Inattentive,” can potentially occur during the transportation of Type B packages and, as such, were not considered as screening criteria. These collisions were included in the database and data was carried forward to create event trees and in calculate collision probabilities.

7.1.4 Other Conditions

Other potential collision contributing factors, including different types of weather and road surface conditions can occur during the transportation of Type B packages; and hence, they were not included in the list of proposed screening criteria.

7.2 Truck Baseline Frequency of Screening Criteria

Once the screening criteria were identified, the next step in selecting the final criteria was to calculate the baseline frequency of contributing factors that could be eliminated from further assessment. **Table 13** shows the proportion of collisions and/or drivers associated with each screening criteria discussed above for truck movements in Ontario.

Table 13: Baseline Frequency of Truck Screening Criteria in Ontario (Truck)

Screening Criteria	Subcategory	Frequencies
Conveyance Used	Heavy Truck	53,613 out of 368,088 total collisions in Ontario (14.5%)
	Truck Tractor	38,296 out of 368,088 total collisions in Ontario (10.4%)
Disobeying Traffic Control Devices	Heavy Truck Driver	174 out of 59,087 heavy truck drivers (0.3%)
	Truck Tractor Driver	104 out of 41,879 truck tractor drivers (0.2%)
Impaired Driving	Heavy Truck Driver	168 out of 59,087 heavy truck drivers (0.3%)
	Truck Tractor Driver	112 out of 41,879 truck tractor drivers (0.3%)

Table 13 shows that truck tractors were involved in approximately 10.4% of collisions in Ontario provincial highways from 2010 to 2019. As expected, the proportion of collisions involving heavy trucks, which included truck tractors, was at a higher level of 14.5%. In addition, 0.3% or less of heavy truck and truck tractor drivers involved in collisions disobeyed traffic control devices. Similar proportions were noted for impaired driving.

These numbers represent a small fraction of truck tractor drivers in Ontario and reiterate that truck tractor drivers are subject to a high level of training and requirements regarding being fit for duty and following the rules of the road.

7.3 Truck Selected Screening Criteria

Once the baseline frequency of screening criteria is defined, the screening criteria selection must be finalized. The applicability of each criterion shown in **Table 13** was assessed via workshops and discussions amidst the project team using expert judgement and leveraging industry experience as well as supported approaches from the literature review.

Regarding conveyance, the truck tractor was more representative of the type of vehicle used to transport Type B packages. The other vehicles included in the 'heavy vehicle' subcategory may be subject to different operating behaviours or route utilization that may not be as representative for these types of shipments.

As such, the truck tractor was chosen as the vehicle type for the probabilistic assessment. This results in a smaller population of data points that are more representative of the types of vehicles of interest to this report.

As for the other screening criteria listed in **Table 13**, a sensitivity analysis was conducted to assess the overall impact of applying the proposed criteria on the probabilities of collision scenarios. The sensitivity analysis was intended to compare the conditional probability of the following two alternatives, using three example scenarios with different vehicle severity damage and object struck:

- **Alternative 1: all-inclusive database**, which includes all truck tractor collisions in Ontario.
- **Alternative 2: subset of database**, which includes all truck tractor collisions in Ontario, excluding the ones with truck tractors drivers disobeying traffic control devices or driving impaired (under the influence of drug and/or alcohol).

As discussed earlier in **Section 4 Methodology**, the probability of a particular collision scenario is the product of all of the branch point fractions that lie on the scenario path, which can be calculated as follows:

$$P_{scenario} = \prod_{i=1}^n P_{Event_i} \quad (1)$$

Where:

$P_{scenario}$	= The conditional probability of a particular collision scenario
P_{Event_i}	= The probability of event i
n	= Total number of events in a scenario

An illustrative example is the calculation of the conditional probability of a truck tractor colliding with a concrete guide rail, which resulted in light damage to the truck. The probability of this particular collision can be calculated as follows:

$$P_{scenario_1} = P_{Collision\ with\ fixed\ object} \times P_{Other\ fixed\ object} \times P_{Light\ damage} \quad (2)$$

Where:

$P_{scenario_1}$	= The conditional probability of a particular collision scenario (i.e., Scenario 1)
$P_{Collision\ with\ fixed\ object}$	= The probability of a collision with a fixed object
$P_{Other\ fixed\ object}$	= The probability of a collision with other fixed objects (i.e., concrete guard rail)
$P_{Light\ damage}$	= The probability of a light damage level

A second example is the calculation of the conditional probability of a truck tractor colliding with another motor vehicle, which resulted in moderate/severe damage to the truck. The probability of this particular collision can be calculated as follows:

$$P_{scenario_2} = P_{Collision\ with\ non-fixed\ object} \times P_{Other\ moving\ vehicle} \times P_{Moderate\ damage} \quad (3)$$

Where:

$P_{scenario_2}$	= The conditional probability of a particular collision scenario (i.e., Scenario 2)
$P_{Collision\ with\ non-fixed\ object}$	= The probability of a collision with a non-fixed object
$P_{Other\ moving\ vehicle}$	= The probability of a collision with another moving vehicle
$P_{Moderate\ damage}$	= The probability of a moderate/severe damage level

Finally, a third example is calculating the conditional probability of a truck tractor running off the road, which resulted in the truck being demolished. The probability of this particular collision can be calculated as follows:

$$P_{\text{scenario}_3} = P_{\text{Non-collision incident}} \times P_{\text{Run off road}} \times P_{\text{Severe damage}} \quad (4)$$

Where:

P_{scenario_3}	= The conditional probability of a particular collision scenario (i.e., Scenario 3)
$P_{\text{Non-collision incident}}$	= The probability of a non-collision incident
$P_{\text{Run off road}}$	= The probability of other non-collision incident (i.e., running off the road)
$P_{\text{Severe damage}}$	= The probability of a demolished damage level

As shown in **Equation (1)**, the conditional probability of a particular collision scenario depends on calculating the event probabilities that constitute the collision scenarios. Therefore, the collision scenarios were broken down into a series of events that comprise a particular collision scenario.

The details for the construction of truck event trees that were used for the basis of conditional probabilities are presented in **Section 9 Calculation of Collision Scenario Probabilities**. Based on the calculated probabilities for each of the events discussed in **Section 9**, an effort was made to compare the probabilities of the above scenarios with and without applying the screening criteria.

Table 14 summarizes the impact of screening criteria on each tree branch and the scenario's final probability.

Table 14: Sensitivity Analysis of Screening Criteria on Sample Scenarios (Tractor Truck)

Scenario No.	Tree Branch	Branch Probability*		Difference in Probabilities
		Alternative 1: All Inclusive Database	Alternative 2: Subset of Database	
Scenario 1	Collisions with a fixed object	0.15417	0.15304	0.7%
	Other fixed object	0.58601	0.58523	0.1%
	Light damage	0.39554	0.39633	0.2%
	Event Probability	0.035735	0.035497	0.7%
Scenario 2	Collisions with a non-fixed object	0.66295	0.66427	0.2%
	Other moving vehicle	0.90733	0.90721	0.0%
	Moderate/severe damage	0.22017	0.21995	0.1%
	Event Probability	0.13243	0.13254	0.1%
Scenario 3	Non-collision incident	0.15886	0.15839	0.3%
	Other non-collision	0.66421	0.66354	0.1%
	Demolished damage	0.16661	0.16545	0.7%
	Event Probability	0.01758	0.01739	1.1%

* Alternative 1 includes all truck tractor collisions in Ontario whereas Alternative 2 includes all truck tractor collisions in Ontario, excluding the ones with truck tractors drivers disobeying traffic control devices or impaired (driving under the influence of drug and/or alcohol).

Table 14 shows that the difference in the impact of applying the screening criteria on the final probabilities of any of the three scenarios provided was less than 1.1%.

These observations were as expected because a small proportion of collisions was associated with each screening criterion, as shown in **Table 13**.

Considering the negligible impact of the screening criteria on the event probabilities, the report utilized a dataset consisting of only truck tractor collisions in Ontario, including instances of truck tractor drivers disobeying traffic control devices or impaired driving, as summarized in **Table 15**.

Table 15 Decision on Screening Criteria

Initial Screening Criteria	Decision
Conveyance Used – Heavy Vehicles vs. Truck Tractors	Applied – Truck tractors only
Driver Action – Disobeying Traffic Control Devices	Not applied – No collisions were excluded by driver action
Driver Condition – Impaired (Influence of Drugs / Alcohol)	Not applied – No collisions were excluded by driver condition

This results in a decrease in the overall data available for use in the event tree analysis stage but falls on the side of conservatism by accounting for more representative conveyances (truck tractors vs all heavy vehicles) and including instances that are unlikely to occur within a used fuel transportation program (e.g., disobeying traffic control signals, impaired driving).

7.4 Train Screening Criteria

In accordance with the analysis of truck movements, a similar approach was employed to review the train collision attributes in the TSB database and determine whether any part of the database should be screened before calculating probabilities.

However, it was determined that unlike trucks (which feature a variety of options for different attributes, including vehicle type, driver action, and driver condition), transportation of Type B packages by trains is subject to fewer variables.

For example, a review of the historical collisions in the TSB database revealed that train collisions involving the transportation of dangerous goods occurred among different subdivision owners, such as CN, CP, Metrolinx, and Ottawa Central Railway, among others.

In addition, there are no specific train or track classifications in the TSB database that would warrant exclusion. It is also noted that the TSB dataset does not provide detailed information regarding factors contributing to collisions, such as the condition or actions of train conductors.

In addition to the above, no evidence exists in the literature for identifying or applying screening criteria for train movements. As such, and based on the above-noted observations, no screening criteria were developed for the transportation of Type B packages using trains. Therefore, the entire dataset of train collisions was utilized for the detailed probabilistic analysis.

Branch 1: Collision Type

For transportation involving truck tractors on Ontario's provincially-managed roadways, all possible events were divided into the following collision types, as discussed in **Section 6.1 Categories of Collision Types**:

- Collisions with non-fixed objects;
- Collisions with fixed objects;
- Non-collision incidents; and
- Other events.

The above collision types form the first branch of the truck event tree, as shown in **Figure 22**.

It is noted that an outlier category ("other event") was comprised of a small proportion of truck tractor collisions with no further information regarding the sequence of events or objects struck. **Section 9 Calculation of Collision Scenario Probabilities** of this report provides the statistics for such events.

Branch 2: Object Struck

The first set of branches was aligned with information in the vehicle event category and was used to create a second set of branches referring to the object struck.

Some categories were consolidated to maintain a manageable number of branches and retain consistency with the event trees in the literature, as illustrated in **Table 16**. An effort was made to combine vehicle event categories with similar characteristics and potential impact on the transport package, as shown in **Table 16**.

Discussions were had regarding areas of interest obtained through consultation with the general public and individuals interested in the transportation of used fuel.

Where it was possible to separate these areas of interest, efforts were made to maintain them as individual branches within the event tree. These topics include incidents involving farm tractors, wild animals, rock faces, snow piles, watercourse, submersion, ditch, rollover, and jackknifing.

Table 16: Consolidation of Ontario Vehicle Event Categories into Object Struck

Branch 1 (Collision Type)	Ontario Vehicle Event Categories	Branch 2 (Consolidated Vehicle Event Category – Object Struck)
Collision with non-fixed object	Railway train struck	Train
	Other motor vehicles	Other moving vehicle
	Streetcar	
	Farm Tractor	Farm Tractor
	Other moveable objects	Other non-fixed/moving objects
	Pedestrian	
	Cyclist	
	Animal-domestic	Animal-wild
	Animal-wild	
Collision with a fixed object	Bridge support	Bridge
	Building/Wall	Other fixed road structure
	Unattended vehicle	Other fixed object
	Culvert	
	Tree/Shrub/Stump	
	Pole-utility	
	Pole-sign/park meter	
	Curb	
	Fence/Noise barrier	
	Cable guide rail	
	Concrete guide rail	
	Steel guide rail	
	Crash cushion	
	Construction marker	
	Debris on road	
	Debris off vehicle	
	Other fixed object	
	Rock face	Rock face
	Snow pile	Snow pile
	Watercourse	Watercourse
	Submersion	Submersion
	Ditch	Ditch
Non-collision	Fire/Explosion	Fire/Explosion
	Load spill	Load spill
	Skidding/Sliding	Other non-collision
	Ran off-road	
	Rollover	Rollover
	Jackknifing	Jackknifing
Other Event	Other Event	Other Event

Branch 3: Collision Configuration

For collisions where the object struck was identified as “bridge support,” it was of particular interest to assess whether the vehicle colliding with the bridge structure left the bridge (run-off) or not (not run-off).

As such, the branch associated with a bridge structure being struck was subdivided into the collision configurations of “run-off” vs. “not run-off.”

The run-off road collision scenario at a bridge represents an extreme scenario of a truck falling some distance. The Lloyd's Register and Sandia Study [2] [7] noted a similar breakdown of collisions on bridges.

Branch 4: Type of Shipment

As indicated in **Section 5.1.1.3 Ontario Dangerous Goods Data**, the MTO database includes a field that identifies whether a vehicle involved in a collision was carrying dangerous goods. As such, the fourth branch of the event tree provides a further breakdown of the truck tractor collisions in terms of type of shipment, by separating collisions involving dangerous goods vs. collisions involving conventional shipments.

Branch 5: Vehicle Severity Damage

The final branch of the event tree categorizes the collisions in terms of vehicle damage severity, which indicates the degree of impact the vehicle was subject to due to the initiating event. As indicated in **Section 6.2.1 Truck Collisions**, six main classifications of vehicle damage severity were available in Ontario's collision dataset, including:

- No damage
- Moderate damage
- Demolished
- Light damage
- Severe damage
- Damage unknown

For the event tree, collisions leading to severe or moderate vehicle damage severity were consolidated and labelled as “Severe/Moderate Damage.” Collisions with demolished vehicle damage severity were grouped separately, representing the most severe incidents with potentially higher impacts on the transport package.

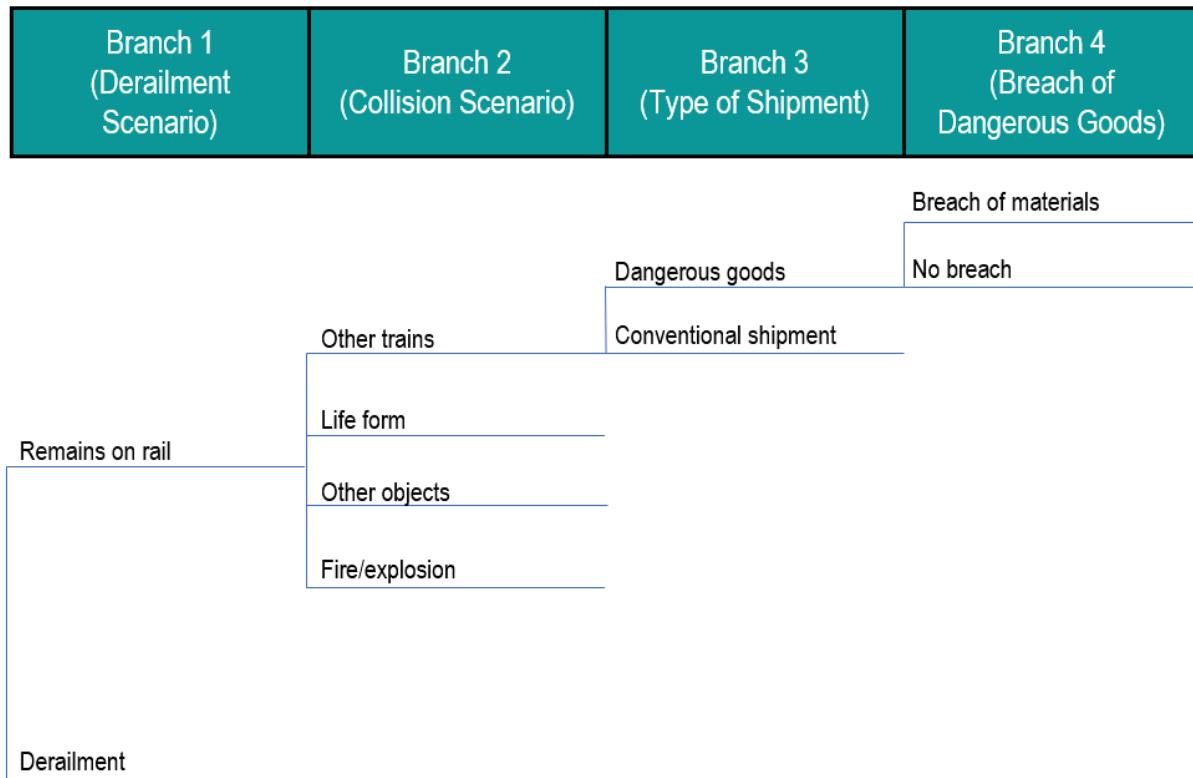
Lastly, incidents leading to no, light, and unknown damage were grouped together, indicative of incidents with less severe impact on the truck tractors and labelled as “Light Damage”.

The resulting truck event tree is shown in **Section 8.2 Truck Event Tree**.

8.1.2 Consolidation of Train Collision Events

The train event tree is comprised of different sets of branches, visually shown as an example in **Figure 23**. Each of the tree branches are described in the following section.

Figure 23: Visual Illustration of Train Event Tree Branches



Branch 1: Derailment Scenario

As noted in **Section 6.1 Categories of Collision Types**, the first set of train event tree branches is based on the following derailment categories:

- The train remains on the rail track; and
- The train derails from the rail track.

Branch 2: Collision Scenario

The first set of branches was aligned with information in the collision description category, which was used to create a second set of branches referring to collision type.

For consistency with the truck event tree and those noted in the literature, some collision scenarios were consolidated, as shown in **Table 17**.

Table 17: Consolidation of TSB Collision Type Categories into Collision Scenarios

Branch 1 (Derailment Scenario)	Collision Type	Branch 2 (Consolidated Collision Scenario)
Remains on rail	Main-track train collision	Other trains
	Non-main-track train collisions	
	Passenger	Life form
	Trespasser	
	Employee	
	Crossing	Other objects
	A collision involving a track unit	
	Rolling stock collision with an abandoned vehicle	
	Rolling stock collision with an object	
	Rolling stock damaged without derailment/collision	
	Fire	Fire/Explosion
	Explosion	
Derailment	Main-track train collision	Other trains
	Non-main-track train collisions	
	Passenger	Life form
	Trespasser	
	Employee	
	Crossing	Other objects
	A collision involving a track unit	
	Rolling stock collision with an abandoned vehicle	
	Rolling stock collision with an object	
	Rolling stock damaged without derailment/collision	
	Fire	Fire/Explosion
	Explosion	
	Main-track train derailment	Main-track train derailment
	Non-main-track train derailment	Non-main-track train derailment

Branch 3: Type of Shipment

The third branch of the event tree provides a breakdown of shipment types, namely dangerous goods and conventional shipments.

Branch 4: Breach of Dangerous Goods

For those collisions involving dangerous goods, the event tree was further broken down to separate those collisions that resulted in the release of materials.

It is noted that the breakdown of shipment types and breach of materials were not included in the train event trees in the Volpe [25] and USNRC studies [8]. In contrast, additional attributes noted in the Volpe Study [25], including speed distribution and surface struck, were unavailable in the TSB dataset and thus not included in the event tree branches of this assessment.

8.2 Truck Event Tree

Based on the above discussion in **Section 8.1.1 Consolidation of Truck Collision Events** and branches of the event tree, the resulting truck event tree is shown in **Table 18**.

Table 18: Truck Event Tree

Collision	Branch 1 (Collision Type)	Branch 2 (Object Struck)	Branch 3 (Collision Configuration)	Branch 4 (Type of Shipment)	Branch 5 (Vehicle Severity Damage)
Truck Collision	Collision with non-fixed object	Train		1) Dangerous goods 2) Conventional shipment	1) Demolished 2) Severe / Moderate Damage 3) Light Damage
		Other moving vehicle			
		Farm tractor			
		Other non-fixed/ moving object			
		Animal-wild			
	Collision with fixed object	Bridge	Run-off		
			No run-off		
		Other fixed road structure			
		Other fixed object			
		Rock face			
		Snow pile			
		Water course			
		Submersion			
		Ditch			
	Non-collision	Fire/Explosion			
		Load spill			
		Other non-collision			
		Rollover			
		Jack knifing			
	Other Event	Other Event			

8.3 Train Event Tree

Based on the above discussion in **Section 8.1.2 Consolidation of Train Collision Events** and branches of the event tree, the resulting truck event tree is shown in **Table 19**.

Table 19: Train Event Tree

Collision	Branch 1 (Derailment Scenario)	Branch 2 (Collision Scenario)	Branch 3 (Type of Shipment)	Branch 4 (Breach of Dangerous Goods)
Train Collision	Remains on rail	Other trains	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Life form	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Other objects	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Fire/Explosion	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
	Derailment	Other trains	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Life form	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Other objects	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Fire/Explosion	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Main-track train derailment	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Non-main-track train derailment	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	

9 Calculation of Collision Scenario Probabilities

Once the branches of the truck and train event trees are identified, the next phase is to describe the steps involved in populating the branches of truck and train event trees with probabilities. This probabilistic analysis informs identifying bounding scenarios, discussed in **Section 10 Sensitivity Assessment & Bounding Scenarios**. In the following sections, the steps involved in the calculation of branch point fractions and conditional probabilities for truck and train movements are discussed.

9.1 Truck Collision Events

9.1.1 Truck Conditional Probabilities

As discussed in **Section 4 Methodology**, the conditional probability of a particular collision scenario is the product of all of the branch point fractions that lie on the scenario path. For example, consider the following collision scenario:

A truck tractor carrying a conventional shipment collided with another moving vehicle. As a result of the collision, the truck was lightly damaged.

The conditional probability of this collision scenario can be expressed as follows:

$$P_{\text{scenario}} = P_{\text{Collision with non-fixed object}} \times P_{\text{Other moving vehicle}} \times P_{\text{Conventional shipment}} \times P_{\text{Light damage}} \quad (5)$$

Where:

P_{scenario}	= The conditional probability of the collision scenario
$P_{\text{Collision with non-fixed object}}$	= The average probability of a collision with non-fixed object
$P_{\text{Other moving vehicle}}$	= The average probability of a collision with other moving vehicle
$P_{\text{Conventional shipment}}$	= The average probability of a collision involving truck tractor carrying conventional shipment
$P_{\text{Light damage}}$	= The average probability of a light damage level

Based on **Equation (5)**, for a total conditional probability in the final column of the event tree, the individual average probabilities from each column are multiplied together. Thus, the average probabilities must be determined before a particular conditional probability of a scenario can be calculated. It is important to note that this report only considers the conditional probability of a collision scenario or the probability of a particular collision scenario occurring **if** a collision happens in the first place.

The average probability of each branch of the event tree within the study period is the average of annual collision probabilities within that particular branch. In the example above, the annual probability of a collision with “non-fixed object” for a particular year was calculated as the frequency of truck tractor collisions with non-fixed objects divided by the total number of truck tractor collisions for that specific year. Following the same logic, the annual probability of a collision with “other moving vehicle” for a particular year was calculated as the frequency of truck tractor collisions with “other moving vehicle” (as a subset of non-fixed object) divided by the total number of truck tractor collisions with non-fixed objects.

Based on the above discussion, the following steps were taken to calculate the conditional probabilities of all scenarios:

- **Step 1:** Calculate annual probabilities for all branches of the event tree.
- **Step 2:** Calculate the average probability of each branch of the event tree within the study period as the average of annual collision probabilities within that particular branch.

- **Step 3:** Calculate the conditional probability of a particular scenario as the product of all of the branch average probabilities that lie on the scenario path.

Using the truck tractor data from MTO's collision database from 2010 to 2019 and the consolidated vehicle event categories in **Table 16**, the annual, average, and conditional probabilities for all collision scenarios were calculated. The above-noted steps are explained further below using an example for illustration purposes.

Step 1: Calculate Annual Collision Probabilities

To provide further details on the calculation process, **Table 20** shows the frequency and probability of truck tractor collisions with "other moving vehicles" as part of "collisions with non-fixed objects."

As shown in **Table 20**, the first step of the process is to calculate the annual collision probabilities for the "other moving vehicles". The annual probability of a collision with "other moving vehicle" for each year in the sixth column of **Table 20** was calculated as the frequency of truck tractor collisions with "other moving vehicle" (fourth column of **Table 20**) divided by the total number of truck tractor collisions with "non-fixed object" (fifth column of **Table 20**). For example, in this table, the annual collision probability of 89.2% in 2010 is the frequency of truck tractor collisions with "other moving vehicle" in 2010 (i.e., 2,850 collisions) divided by the total number of truck tractor collisions with "non-fixed object" in 2010 (i.e., 3,196 collisions).

Following the same process, the annual collision probabilities were calculated for all branches of the truck event tree.

Step 2: Calculate Average Collision Probabilities

The average probability of collisions with "other moving vehicles" during the whole of the study period (i.e., 90.7%) is calculated as the average annual probabilities, listed in the sixth column of **Table 20**. The last column represents the standard deviation of the annual probabilities listed in the sixth column, which will be used for sensitivity analysis. This is discussed in **Section 10 Sensitivity Assessment & Bounding Scenarios** of the report.

As noted earlier in this report, the calculated probabilities do not represent the probability of a truck collision occurring. Rather, they state the probability of the exact sequence of collision events happening, with a starting assumption that a truck collision has taken place.

Table 20: Example Calculation of Truck Collision Probability (with Other Moving Vehicles)

Collision Type	Object Struck	Year	Frequency of Collisions		Annual Probability	Average Probability	Standard Deviation of Probability
			Other moving vehicle	All collisions with a non-fixed object			
Collision with a non-fixed object	Other moving vehicle	2010	2,850	3,196	89.2%	90.7%	1.48%
		2011	3,229	3,596	89.8%		
		2012	2,716	3,071	88.4%		
		2013	3,228	3,611	89.4%		
		2014	3,540	3,866	91.6%		
		2015	2,982	3,290	90.6%		
		2016	2,855	3,127	91.3%		
		2017	3,186	3,456	92.2%		
		2018	3,359	3,604	93.2%		
		2019	3,367	3,693	91.2%		

Following the same approach, the average probabilities for different collision types, object struck, collision configuration, type of shipment, and vehicle damage severity were calculated. The results are shown in **Table 21**.

The average probabilities for vehicle damage severity correlate to the object struck. For example, the proportion of trucks being “demolished” as a result of a collision with a “train” is 33.3%, while the same damage level for truck collisions with “other moving vehicles” is 2.7%.

In other words, the likelihood of demolished collisions depends on the impact object. In contrast, the type of shipment is not correlated with the object struck, and as such, the conditional probabilities for this branch remained the same for different scenarios.

As noted in **Section 4 Methodology**, a key feature of an event tree is that the sum of all fractions at a given branch point equals one. However, some exceptions may occur due to rounding the calculated results to three decimal points. For example, the fractions for the “collision with non-fixed object” in **Table 21** are:

- Collision with train = 0.00009 (0.009%)
- Collision with other moving vehicle = 0.907 (90.7%)
- Collision with farm tractor = 0.00029 (0.029%)
- Collision with other non-fixed / moving object = 0.030 (3.0%)
- Collision with animal-wild = 0.063 (6.3%)

Based on the above, the sum of all fractions for collision with non-fixed object type is:

$$0.00009 + 0.907 + 0.00029 + 0.030 + 0.063 = 1.00038$$

For the purpose of this report, the above-noted discrepancies were considered acceptable, representing the errors in the magnitude of 0.001 (or 0.1%) in the calculation of conditional probabilities.

Table 21: Calculated Collision Probabilities for Different Branches of the Event Tree (Truck Tractor)

Collision Type	Average probability	Object Struck	Average probability	Collision Config.	Average probability	Type of Shipment	Average probability	Vehicle Severity Damage	Average probability
Collision with a non-fixed object	66.3%	Train	<0.1% (0.009%)			Dangerous goods Conventional shipment	Dangerous goods (0.3%) Conventional shipment (99.7%)	Demolished	33.3%
								Severe/Moderate Damage	66.7%
								Light Damage	0.0%
		Other moving vehicle	90.7%					Demolished	2.7%
								Severe/Moderate Damage	22.0%
								Light Damage	75.3%
		Farm Tractor	<0.1% (0.029%)					Demolished	14.3%
								Severe/Moderate Damage	57.1%
								Light Damage	28.6%
		Other non-fixed / moving objects	3.0%					Demolished	2.1%
								Severe/Moderate Damage	36.3%
								Light Damage	61.6%
Animal-wild	6.3%			Demolished	1.2%				
				Severe/Moderate Damage	54.4%				
				Light Damage	44.5%				
Collision with a fixed object	15.4%	Bridge	1.0%	Run-off	4.0%			Demolished	25.0%
				No run-off	96.0%			Severe/Moderate Damage	58.3%
								Light Damage	16.7%
				Other fixed road structure	0.2%				
		Severe/Moderate Damage	35.6%						
		Light Damage	55.6%						
		Demolished	0.0%						
		Other fixed object	58.7%					Severe/Moderate Damage	71.9%
								Light Damage	28.1%
								Demolished	15.0%
								Severe/Moderate Damage	45.5%
		Rock face	3.2%					Light Damage	39.6%
								Demolished	44.3%
								Severe/Moderate Damage	46.7%
								Light Damage	9.1%

Collision Type	Average probability	Object Struck	Average probability	Collision Config.	Average probability	Type of Shipment	Average probability	Vehicle Severity Damage	Average probability
		Snow pile	3.4%					Demolished	4.2%
								Severe/Moderate Damage	54.5%
								Light Damage	41.2%
		Watercourse	0.1%					Demolished	21.4%
								Severe/Moderate Damage	42.9%
								Light Damage	35.7%
		Submersion	0.1%					Demolished	93.8%
								Severe/Moderate Damage	6.3%
								Light Damage	0.0%
		Ditch	33.2%					Demolished	17.2%
								Severe/Moderate Damage	58.2%
								Light Damage	24.6%
Non-collision	15.9%	Fire / Explosion	2.8%					Demolished	52.3%
								Severe/Moderate Damage	33.6%
								Light Damage	14.1%
		Load spill	2.8%					Demolished	19.4%
								Severe/Moderate Damage	42.0%
								Light Damage	38.6%
		Other non-collision	66.4%					Demolished	16.7%
								Severe/Moderate Damage	56.1%
								Light Damage	27.2%
		Rollover	12.8%					Demolished	36.1%
								Severe/Moderate Damage	56.4%
								Light Damage	7.5%
Jackknifing	15.2%			Demolished	11.2%				
				Severe/Moderate Damage	65.5%				
				Light Damage	23.3%				
Other Event	2.4%	Other Event	100%					Demolished	1.3%
						Severe/Moderate Damage	6.8%		
						Light Damage	91.9%		

Step 3: Calculate Conditional Probabilities

After the calculation of the branch point fractions and collision scenario probabilities for all the branches, the conditional probabilities for all collisions scenarios were calculated using **Equation (6)** below:

$$P_{scenario} = \prod_{i=1}^n \bar{P}_{Event_i} \quad (6)$$

Where:

$P_{scenario}$ = The conditional probability of a particular collision scenario

$\bar{P}_{Event_i}$ = The average probability of event i

n = Total number of events in a scenario

9.1.2 Top Five Scenarios with Highest Conditional Probabilities for Truck Collisions

The full list of 120 truck tractor scenarios, including the average and conditional probabilities, can be found in **Appendix A**. It is noted that all truck tractor scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

Table 22 presents the top five scenarios with the highest conditional probabilities for collisions involving truck tractors. These scenarios comprise 71.9% of the total conditional probabilities of truck tractor collisions.

Given the low occurrence of truck tractor collisions carrying dangerous goods in Ontario (less than 0.3%, as shown in **Table 21**), the conditional probability of those scenarios involving dangerous goods were generally lower than those scenarios involving conventional shipments, and as such, did not appear among the top five scenarios in **Table 22**.

Table 22: Top Five Scenarios with Highest Conditional Probabilities (Truck Tractor)

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Ranking
Collision with a non-fixed object	Other moving vehicle	Conventional	Light	45.2%	1
Collision with a non-fixed object	Other moving vehicle	Conventional	Severe / Moderate	13.2%	2
Non-collision	Other non-collision (skidding/sliding or running off-road)	Conventional	Severe / Moderate	5.9%	3
Collision with a fixed object	Other fixed objects (e.g., tree, culvert, guide rail)	Conventional	Severe / Moderate	4.1%	4
Collision with a fixed object	Other fixed object	Conventional	Light	3.6%	5

9.2 Train Collision Events

9.2.1 Train Conditional Probabilities

The respective branches' fraction of the train event tree was calculated using the train data from the TSB collision database from 2010 to 2019 and the consolidated event categories in **Table 17**.

The average train collision probabilities for the train event tree branches were calculated in a similar approach to those for trucks discussed above in **Section 9.1.1** and the example shown in **Table 20**. The results are shown in **Table 23**.

Table 23: Calculated Collision Probabilities for Different Branches of the Event Tree (Train)

Derailment Scenario	Average Probability	Collision Scenario	Average Probability	Type of Shipment	Average Probability	Breach of Dangerous Goods	Average Probability
Remains on rail	36.6%	Other trains	15.0%	Dangerous goods Conventional shipment	Dangerous goods (12.5%) Conventional shipment (87.5%)	Breach	0.0%
		Life form	19.4%			No breach	100.0%
						Breach	0.0%
						No breach	100.0%
						Breach	1.2%
		Other objects	57.1%			No breach	98.8%
						Breach	0.3%
						No breach	99.7%
Breach	0.1%						
Derailment	63.4%	Other trains	6.0%			No breach	99.9%
		Life form	<0.1% (0.04%)			Breach	0.0%
						No breach	100.0%
		Other objects	3.4%			Breach	0.2%
						No breach	99.8%
		Fire/Explosion	<0.1% (0.01%)			Breach	0.0%
						No breach	100.0%
		Main-track train derailment	13.0%	Breach	2.9%		
No breach	97.1%						
Breach	0.6%						
No breach	99.4%						

In the absence of collision damage level in the TSB database, the breach of materials can be a surrogate measure for the damage taken by trains carrying dangerous goods. The proportion of collisions with and without breach of dangerous goods differed for various derailment and collision scenarios.

After calculating the branch point fractions and collision scenario probabilities for all the branches, the conditional probabilities for all collision scenarios were calculated using **Equation (6)**.

9.2.2 Top Five Scenarios with Highest Conditional Probabilities for Train Collisions

The full list of 30 train scenarios, including the average and conditional probabilities, can be found in Appendix B. Like truck tractors, all train scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each collision scenario.

Table 24 presents the top five scenarios with the highest conditional probabilities for collisions involving trains. These scenarios comprise 80.9% of the total conditional probabilities of train collisions.

Table 24: Top Five Scenarios with Highest Conditional Probabilities (Train)

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Ranking
Derailment	Non-main-track train derailment	Conventional	-	43.0%	1
Remains on rail	Other objects (e.g., abandoned vehicle, track unit)	Conventional	-	18.3%	2
Derailment	Main-track train derailment	Conventional	-	7.2%	3
Remains on rail	Life form	Conventional	-	6.2%	4
Derailment	Non-main-track train derailment	Dangerous goods	No breach	6.1%	5

10 Sensitivity Assessment & Bounding Scenarios

Once the conditional probabilities are calculated, the next step is determining the potential bounding collisions. The bounding collision scenarios are the most probable and severe transportation collisions that would encompass, or ‘bound,’ other transportation-related incidents that might occur, including those of lesser severity. This is discussed in **Section 10.1 Potential Bounding Collision Scenarios**.

In conjunction with identification of bounding scenarios, an effort was made to conduct a sensitivity analysis and calculate an upper bound of the probabilities, representing the worst-case outcomes of the probabilistic assessments. The sensitivity analysis was conducted for all incidents involving truck tractors and trains, including bounding scenarios. The discussion on sensitivity analysis is presented in **Section 10.2 Sensitivity Analysis**. This is followed by discussions on emerging themes in **Section 10.3 Emerging Themes of Interest** that may be of interest to communities and members of the public regarding safety aspects associated with transporting Type B packages and radioactive materials.

10.1 Potential Bounding Collision Scenarios

Two components should be considered in the development of bounding collisions:

- 1) the probability of a collision scenario occurring, and
- 2) the resulting outcomes or consequences of a collision if it were to occur.

The first component can be captured in conditional probabilities, while the severity of consequences can be represented by parameters such as “vehicle damage severity”.¹⁴

10.1.1 Potential Bounding Truck Scenarios

The potential bounding collision scenarios for tractor trucks were selected from the long list of 120 truck scenarios with the highest likelihood of occurrence, combined with the best estimation of the severity of outcome, which can be expressed by vehicle damage severity for truck tractors.

Building on the above and for the purpose of this report, five scenarios with the highest conditional probabilities with vehicle damage severity of “demolished” and “severe/moderate damage” levels were selected. Collisions with “demolished” and “severe/moderate damage” levels refer to those which are more severe than collisions resulting in “light damage” to the truck tractor.

Different attributes of the potential bounding scenarios are shown in **Table 25**.

¹⁴ While this analysis is focused on the severity of damage to the conveyance, it is important to note that damage to a conveyance does not necessarily translate to damage or breach of a Type B package. Type B transport packages are designed, tested, and certified by the Canadian nuclear regulator (CNSC) to withstand credible accident conditions i.e., they must shield and contain contents under hypothetical accident conditions for all modes of transport and meet stringent regulatory requirements based on international standards.

Table 25: Potential Bounding Scenarios (Truck Tractor)

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Ranking
with a non-fixed object	Other moving vehicle	Conventional shipment	Severe / Moderate	13.2%	2
Non-collision	Other non-collision			5.9%	3
with a fixed object	Other fixed object			4.1%	4
with a fixed object	Ditch			3.0%	6
with non-fixed object	Animal-wild			2.3%	8
Non-collision	Other non-collision	Conventional shipment	Demolished	1.8%	11
with non-fixed object	Other moving vehicle			1.6%	12
with a fixed object	Other fixed object			1.4%	14
with fixed object	Ditch			0.9%	18
Non-collision	Rollover			0.7%	19

10.1.2 Potential Bounding Train Scenarios

The potential train bounding scenarios can be selected from the long list of 30 train scenarios based on the following rules:

- Derailment scenarios may have a more severe impact on the package than those scenarios where the train remained on the rail.
- Among derailment scenarios, the impact of those carrying “dangerous goods” would be higher than conventional shipments. Given the nature of the shipment, dangerous goods may have a higher capacity to cause harm to life forms and the environment when involved in uncontrolled spills and/or collisions than conventional goods.
- Collision scenarios involving “main track train derailment,” “other trains,” “other objects,” and “fire/explosion” supersede those scenarios with “life form” and “non-main-track train derailment” collisions.

It is assumed that “non-main-track train derailment” collisions are mostly those incidents that occur at rail yards, with lower speeds, and as such, the potential impact on the packages in question would be minimal. In contrast, collisions involving “main track train derailment” would occur at higher speeds, which could translate to a potentially more severe impact on the Type B packages.

Collisions involving “life form”, as tragic as they may be, would have a minimal impact on the Type B packages, and as such, were replaced by more severe scenarios, such as collisions involving “other trains,” “other objects,” and “fire/explosion”.

Table 26 shows the potential bounding train scenarios with the highest conditional probabilities.

Table 26: Potential Bounding Scenarios (Train)

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Ranking
Derailment	Main-track train derailment	Dangerous goods	No breach	1.0%	11
Derailment	Other trains		No breach	0.5%	14
Derailment	Other objects		No breach	0.3%	16
Derailment	Main-track train derailment		Breach of materials	<0.1% (0.03%) ¹⁵	18
Derailment	Fire/Explosion		No breach	<0.1% (0.001%)	24
Derailment	Other trains		Breach of materials	<0.1% (0.0007%)	25
Derailment	Other objects		Breach of materials	<0.1% (0.0005%)	26
Derailment	Fire / Explosion		Breach of materials	0.0	27

10.2 Sensitivity Analysis

10.2.1 Sensitivity Analysis Objective and Approach

The sensitivity analysis aims to calculate an upper bound of the probabilities, representing the worst-case outcomes of the probabilistic assessments. The results of the sensitivity analysis provide insights for the degree of uncertainty in the probabilistic analysis.

To achieve this, the associated average for the branch point probabilities (e.g., 90.7% in **Table 20**) was added with the standard deviation of the annual branch probabilities (e.g., 1.48% in **Table 20**) to calculate the upper bound of probabilities.

Next, the upper bound probabilities that constitute a scenario were multiplied together to calculate the upper bound of the conditional probabilities, as shown in the proceeding equations:

$$P_{Event_i}^{Upper} = \bar{P}_{Event_i} + SD_{Event_i} \quad (7)$$

$$P_{scenario}^{Upper} = \prod_{i=1}^n P_{Event_i}^{Upper} \quad (8)$$

Where:

- $\bar{P}_{Event_i}$ = The average probability of event i
- SD_{Event_i} = The standard deviation of event i
- $P_{Event_i}^{Upper}$ = The upper bound probability of event i
- $P_{scenario}^{Upper}$ = The upper bound of the conditional probability of a particular collision scenario
- n = Total number of events in a scenario

¹⁵ The Lac-Mégantic rail incident is classified as the “main-track train derailment” scenario, involving dangerous goods, and breach of materials. The creation of the event tree is based on identification of contributing factors and causes of collisions, rather than consequences. The fire and explosion that occurred during the Lac-Mégantic incident was a consequence of train derailment, and as such, was not classified as “fire/explosion” collision scenario.

The above calculations are shown in an example scenario in **Table 27**, which includes a truck tractor collision with another moving object carrying a conventional shipment, resulting in severe/moderate damage to the truck tractor.

The average (third column) and standard deviation of probabilities (fourth column) were calculated separately for different events in this scenario, following the same process shown in **Table 20**.

The upper bound of event probabilities (fifth column) and upper bound of conditional probability (seventh column) were calculated using the formulas in **Equations (7)** and **(8)**, respectively.

Table 27: Example Calculation of Upper Bound Probabilities

Event Attributes	Example Scenario Attributes	Average Probability	Standard Deviation	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability
Collision Type	Collision with a non-fixed object	66.3%	3.0%	69.3% (66.3%+3.0%)	13.2% (66.3%×90.7% × 99.7%×22.0%)	15.4% (69.3%×92.2% × 99.9%×24.0%)
Object Struck	Other moving vehicle	90.7%	1.5%	92.2% (90.7%+1.5%)		
Type of Shipment	Conventional shipment	99.7%	0.2%	99.9% (99.7%+0.2%)		
Vehicle Severity Damage	Severe/Moderate Damage	22.0%	2.0%	24.0% (22.0%+2.0%)		

Based on the calculations shown in **Table 27**, the upper bound of the conditional probability for this scenario was increased by approximately 15%, from 13.2% to 15.4%.

10.2.2 Upper Bound Probability of Bounding Scenarios

Following the approach discussed above, **Appendix A** and **Appendix B** summarize the upper bound of conditional probabilities for all incidents involving truck tractors and trains. For brevity, the sensitivity analysis was focused on potential bounding scenarios.

Table 28 and **Table 29** present a one-to-one comparison between the conditional probabilities and the upper bound values for truck and train bounding scenarios.

The difference between the two values for each bounding scenario was also reported in these tables, representing a degree of uncertainty in calculating probabilities.

Table 28: Sensitivity Analysis on Truck Bounding Scenarios

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Upper Bound of Conditional Probability	Difference (%)	Rank
Collision with a non-fixed object	Other moving vehicle	Conventional shipment	Severe / Moderate Damage	13.2%	15.4%	16.3%	2
Non-collision	Other non-collision			5.9%	7.4%	24.5%	3
Collision with a fixed object	Other fixed object			4.1%	4.9%	19.0%	4
Collision with a fixed object	Ditch			3.0%	3.7%	25.2%	6
Collision with a non-fixed object	Animal-wild			2.3%	4.4%	93.6%	8
Non-collision	Other non-collision	Conventional shipment	Demolished	1.8%	2.5%	41.8%	11
Collision with a non-fixed object	Other moving vehicle			1.6%	2.0%	23.1%	12
Collision with a fixed object	Other fixed object			1.4%	1.8%	30.1%	14
Collision with a fixed object	Ditch			0.9%	1.2%	40.5%	18
Non-collision	Rollover			0.7%	1.1%	48.2%	19

Table 29: Sensitivity Analysis on Train Bounding Scenarios

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Upper Bound of Conditional Probability	Difference (%)	Rank
Derailment	Main-track train derailment	Dangerous goods	No breach	1.0%	1.4%	41.2%	11
Derailment	Other trains		No breach	0.5%	0.6%	31.1%	14
Derailment	Other objects		No breach	0.3%	0.4%	37.5%	16
Derailment	Main-track train derailment		Breach of materials	<0.1% (0.03%)	<0.1% (0.09%)	186.8%	18
Derailment	Fire/Explosion		No breach	<0.1% (0.001%)	<0.1% (0.005%)	383.1%	24
Derailment	Other trains		Breach of materials	<0.1% (0.0007%)	<0.1% (0.003%)	306.6%	25
Derailment	Other objects		Breach of materials	<0.1% (0.0005%)	<0.1% (0.002%)	328.6%	26
Derailment	Fire / Explosion		Breach of materials	0.0	0.0	-	28

For truck bounding scenarios, collisions with wild animals with severe/moderate impact on the truck carrying conventional shipment show the largest relative increase, by 93.6%, which indicates the highest uncertainty. The level of uncertainty for other truck-bounding scenarios ranged from 16.3% to 48.2%.

For train scenarios with conditional probabilities higher than 0.1%, the upper bound of conditional probabilities was between 31.1% to 41.2% higher than conditional probabilities.

As expected, the uncertainties for those scenarios with very low probabilities were significantly higher than other bounding scenarios. This is due to such events occurring so rarely that a one or two instance increase per year may double or triple the conditional probability of that event for that given year.

In summary, the percent difference in the conditional probability and the upper bound represents a degree of uncertainty, and very low conditional probabilities come with a high degree of uncertainty.

10.3 Emerging Themes of Interest

One of the primary goals of this report was to identify emerging themes that may be of interest to communities and members of the public regarding the safe transport of Type B packages and radioactive materials. The themes identified from the available data are discussed below.

10.3.1 Emerging Themes of Interest for Trucks

The analysis below considers conditional probability of collisions scenarios involving a truck tractor. It is important to note that conditional probability is the probability of a particular collision scenario occurring if a collision happens in the first place. The conditional probability discussed herein does not represent the likelihood that a collision could lead to a consequence (such as breach of a Type B transportation package) or potential impact (e.g., environmental impacts, health effects or injuries). The estimated number of events are determined by applying the highest range of conditional probabilities to the approximate average of truck tractor collisions per year in Ontario.

10.3.1.1 Incidents on Bridges

It is of particular interest to assess the probabilities of collisions on bridges, including the probability that a collision leads to run-off from the bridge. In accordance with this interest, the analysis captured collisions with bridge supports in the truck event tree, including run-off vs. non-run-off scenarios.

According to the long list of scenarios in Appendix A, the conditional probability of truck tractor collisions on bridges, resulting in a “run-off-road” event, ranged from 2.77×10^{-8} to 3.75×10^{-5} , depending on the collision configuration, type of shipment, and vehicle severity damage. For “non-run-off road” events, the conditional probability ranged between 3.48×10^{-7} and 8.49×10^{-4} . As shown in **Table 21**, 96% of collisions with bridge structure result in non-run-off road, and as such, the conditional probabilities of scenarios with non-run-off road events were higher than those scenarios with run-off road events.

The non-run-off road scenario with the highest probability of 8.49×10^{-4} and ranking of 35 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment collided with a bridge structure with no run-off-road. As a result of the collision, the truck was lightly damaged.

In terms of conditional probabilities, the probability of this non-run-off scenario occurring was approximately 1 in 1,177 if a truck collision occurred in the first place. An approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, would amount to 3 to 4 events per year in Ontario.

The run-off road scenario with the highest probability of 3.75×10^{-5} and ranking of 65 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment collided with a bridge structure. As a result of the collision, the truck ran off-road and was severely/moderately damaged.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 26,694 if a truck collision occurred in the first place. An approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, would amount to 0.15 events per year in Ontario, or one event per 6 to 7 years in Ontario.

10.3.1.2 Collisions Resulting in Run-off into Bodies of Water

Collisions resulting in run-off-road and into bodies of water were captured in the truck event tree as incidents resulting in “watercourse” and “submersion.”

For collisions involving “watercourse,” the conditional probability of truck tractor collisions ranged from 9.85×10^{-8} to 7.62×10^{-5} , depending on the type of shipment and vehicle severity damage. The scenario with the highest probability of 7.62×10^{-5} and ranking of 53 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment ran into the watercourse. As a result of the collision, the truck was severely/moderately damaged.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 13,118 if a truck collision occurred in the first place. This probability was a fraction of the probability of the scenario with the highest ranking (0.495), or 0.015%.

Similarly, for collisions involving “submersion,” the conditional probability ranged from zero to 1.13×10^{-4} . The scenario with the highest probability of 1.13×10^{-4} and ranking of 47 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment submerged into the water. As a result of the collision, the truck was demolished.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 13,118 if a truck collision occurred in the first place. Given an approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, this would result in approximately one collision every three years.

10.3.1.3 Collisions along Significant Bodies of Water

The location of the collision concerning the bodies of water is not reported in the Ontario collision database and could not be included in the event tree. Collisions along significant bodies of water would be a subset of the entire collision datasets, and the conditional probability of all scenarios for truck tractor collisions along bodies of water would be less than the probabilities listed in **Appendix A**.

In other words, truck tractors' all-inclusive data generate higher probabilities than a subset of data and supersedes scenarios generated from a smaller database.

10.3.1.4 Collisions in Urban vs. Rural Areas

Like above, the land use attributes are not reported in the Ontario collision database and could not be included in the event tree. However, collisions occurring on provincial highways within urban or rural areas would be a subset of the collision dataset.

As such, the conditional probability of all scenarios involving truck tractor collisions, specifically in an urban or a rural setting would be less than the probabilities listed in **Appendix A**, including collisions in urban and rural areas. The all-inclusive data for truck tractors generate higher probabilities than a subset of data and supersede scenarios generated from smaller databases within either urban or rural areas.

10.3.1.5 Collisions in Icy/Snow/Slush Conditions

The Ontario dataset includes information on the road surface condition during the collision. As noted in **Section 7 Screening Criteria**, this information has not been used in the event tree, but given the cold winter climate throughout Canada, it is important to discuss such collision statistics in the context of this project.

As shown in **Table 30**, of all truck tractors involved in collisions between 2010 and 2019, close to 20% were involved in collisions on icy/snow/slush surface conditions. Of these, 6% and 38% resulted in a vehicle damage severity that was demolished and severe/moderate damage, respectively.

In contrast, considering all truck tractors involved in collisions, the fraction of those incidents which resulted in a vehicle damage severity that was demolished, and severe/moderate damage was 4% and 28%, respectively.

Based on these statistics, it can be concluded that the likelihood of demolished or severely damaged vehicles is higher on icy/snowy/slushy roads compared to the entire dataset. It is important to note that these results do not indicate that the conditional probability of truck tractors on icy/snowy/slushy roads is higher than the values listed in **Appendix A**.

It simply suggests that if a truck tractor were involved in a collision on icy/snowy/slushy roads, the likelihood of the truck being demolished or severely/moderately damaged would be higher.

Table 30: Summary of Truck Tractor Involved in Collisions Icy/Snow/Slush Surface Condition

Year	Percentage of Truck Tractor involved in Collisions on Icy/Snow/Slush Surface Condition	Percentage of Truck Tractor involved in Collisions		Percentage of Truck Tractor involved in Collisions on Icy/Snow/Slush Surface Condition	
		Demolished	Severe/Moderate Damage	Demolished	Severe/Moderate Damage
2010	16%	5%	26%	5%	36%
2011	20%	4%	27%	6%	32%
2012	19%	5%	27%	7%	35%
2013	25%	5%	30%	4%	37%
2014	30%	5%	31%	6%	42%
2015	17%	4%	25%	5%	38%
2016	18%	4%	28%	5%	42%
2017	17%	4%	27%	8%	39%
2018	19%	4%	29%	5%	39%
2019	23%	4%	28%	5%	40%
Average	20%	4%	28%	6%	38%

10.3.1.6 Collisions in Two-Lane vs. Multi-Lane Highways

The Ontario dataset includes information regarding the roadway type, i.e., two-lane vs. multi-lane and the presence of a physical barrier between the two directions of traffic, i.e., divided¹⁶ vs. undivided¹⁷ highways. Like road surface conditions, this information has not been used in the event tree, but it is essential to create a better understanding of the percentage of truck tractor involved in collisions in Ontario using different approaches.

As shown in **Table 31** and **Table 32**, of all truck tractors that were involved in collisions between 2010 and 2019, 26% of them were involved in collisions that occurred on 2-lane roadways (i.e., 1 lane per direction), and 61% of them were involved in collisions that occurred on multi-lane roadways (i.e., 2 or more lanes per direction). These observations are as expected since multi-lane roadways carry higher traffic volumes, increasing the likelihood of collisions.

¹⁶ A highway divided into separate streams by a median strip with a physical barrier (e.g., guide rails, fences, walls) or median stripe(s) of unpaved ground without restraining barriers (e.g., grass median with drainage ditch)

¹⁷ An undivided highway for traffic in opposite directions includes roads with only serrated concrete strips (singing medians) or painted lines between opposing lanes.

In terms of the vehicle damage severity, the statistics listed in the tables suggest that:

- The proportion of truck tractors involved in demolished and severe/moderate damage collisions on 2-lane roadways was higher than in multi-lane roadways.
- Collisions occurring on undivided roadways are more severe when compared to the ones that occurred on divided roadways, presumably because truck tractors involved in collisions on undivided roadways are more likely to collide with vehicles from opposing roadway's travel directions.

Table 31: Summary of Truck Tractors Involved in Collisions Occurred on 2-Lane Roadways

Year	Percentage of Truck Tractor Involved in Collisions on 2-lane Roadways			Percentage of Truck Tractor Involved in Collisions on <u>Undivided</u> 2-lane Roadways			Percentage of Truck Tractor Involved in Collisions on <u>Divided</u> 2-lane Roadways		
	Total ¹⁸	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage
2010	26%	10%	40%	20%	11%	42%	6%	6%	33%
2011	27%	8%	38%	21%	8%	41%	6%	6%	30%
2012	29%	8%	37%	23%	7%	39%	6%	10%	30%
2013	29%	8%	40%	23%	9%	42%	7%	5%	33%
2014	27%	7%	42%	20%	7%	43%	7%	6%	38%
2015	25%	8%	40%	19%	8%	42%	6%	8%	33%
2016	24%	7%	43%	17%	8%	45%	7%	5%	38%
2017	25%	9%	42%	18%	9%	42%	7%	7%	39%
2018	25%	8%	43%	17%	8%	45%	8%	8%	38%
2019	27%	6%	42%	18%	6%	46%	9%	6%	33%
Average	26%	8%	41%	19%	8%	43%	7%	7%	35%

¹⁸ The "Total" presented in Table 31 and Table 32 are the total percentages of truck tractors that were involved in collisions under the described scenario (e.g., Collisions on Undivided 2-lane Roadways)

Table 32: Summary of Truck Tractors Involved in Collisions Occurred on Multi-Lane Roadways

Year	Percentage of Truck Tractors Collisions on Multi-Lane Roadways			Percentage of Truck Tractors Collisions on <u>Undivided</u> Multi-Lane Roadways			Percentage of Truck Tractors Collisions on <u>Divided</u> Multi-Lane Roadways		
	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage
2010	56%	3%	24%	6%	7%	31%	50%	3%	23%
2011	54%	4%	25%	5%	6%	36%	48%	3%	24%
2012	54%	4%	26%	6%	7%	29%	48%	4%	25%
2013	57%	4%	26%	5%	5%	32%	52%	4%	26%
2014	63%	4%	30%	5%	6%	33%	58%	4%	29%
2015	66%	2%	22%	4%	4%	35%	62%	2%	21%
2016	67%	3%	23%	3%	1%	29%	63%	3%	23%
2017	65%	3%	22%	4%	4%	35%	61%	3%	22%
2018	65%	2%	25%	4%	4%	28%	61%	2%	25%
2019	62%	3%	23%	4%	4%	31%	59%	3%	23%
Average	61%	3%	25%	5%	5%	32%	56%	3%	24%

10.3.2 Emerging Themes of Interest for Trains

The emerging themes for train movements are mainly focused on derailments with mixed materials and or collisions between multiple trains that have mixed materials, such as the 1979 Mississauga train derailment.

While the importance of such events is recognized, the TSB database does not provide the breakdown of collisions with mixed materials, or the UN number recorded as part of the breached dangerous goods parameter on the rail dataset. Having said that, any specific collision scenario (such as the 1979 Mississauga train derailment) is a subset of the entire collision datasets, and the conditional probability of those scenarios would be less than the probabilities listed in **Appendix B**.

In other words, train's all-inclusive data generate higher probabilities than a subset of data and supersedes scenarios generated from a smaller database.

11 Benchmarking

11.1 Benchmarking Against Similar Road Transportation Assessments

As a benchmarking exercise, this report compares the results of the road transportation analyses described in the previous sections with other studies described in the literature review. These comparisons included an examination of the probabilities of collision types compared to other data sets in the first and second branches of the report event trees, the probabilities of like sequences of events along similar event tree pathways, and the rankings of analogous sequences of events among different studies. There were no applicable rail transportation analyses to provide an acceptable benchmark.

The benchmarking exercises considered the initial branch (Collision Type) and second branch (Object Struck) for the Modal Study from 1987 [5], NUREG/CR-6672 from 2000, and the Lloyd's Register report from 2019 [2]. The Modal Study is the oldest of the studies and uses data from U.S. roadways. NUREG/CR-6672 uses U.S. truck collision data from 1996 through 2000.

The Lloyd's Register report uses data from 2011-2015 from Transport Canada's National Collision Database.

A summary of the collision probabilities from these and the current report is provided in **Table 33**. The data indicate good agreement with the newer NUREG/CR-6672 and Lloyd's Register reports and suggest that the Ontario data used for the current report is reasonably representative of truck collision data in the U.S. and Canada as a whole.

Table 33: Summary of Truck Collision Benchmarking

Branch 1: Collision Type	Branch 2: Object Struck	Modal Study (1987)	NUREG/CR-6672 (Sandia, 2000)	Lloyd's Register (2019)	NWMO (Current Report, 2023)
Collision with a non-fixed object	Train	1.0%	0.1%	0.1%	0.01%
	Other vehicles	88.0%	94.1%	88.1%	90.7%
	Other non-vehicle	11.0%	5.8%	11.8%	9.3%
Collision with a fixed object	Bridges	6.0%	6.4%	2.5%	1.0%
	Ditch/culvert	42.0%	24.4%	20.3%	33.2%
	Embankment/water	-	4.6%	1.4%	6.8%
	Other road structure	6.0%	-	4.2%	0.2%
	Other fixed object	46.0%	63.6%	72.0%	58.7%
Non-collisions	Fire/explosion	4%	5%	2.6%	2.8%
	Other non-collision	35.0%	95%	97.4%	66.4%
	Rollover/jackknife	53.0%			28.0%

The proceedings graphs also represent these comparisons in **Figure 24**, **Figure 25** and **Figure 26**. Figure 24 demonstrates that collisions with other vehicles are the dominant collision type for the three past studies and current report.

Figure 25 demonstrates that most fixed objects struck in truck collisions fall into the “Other fixed objects” category. The data also show that collisions with defined structures such as bridges (discussed as a theme of interest in **Section 10.3.1.1 Incidents on Bridges**) are generally consistent and within the same order of magnitude for each dataset. However, there is greater inconsistency concerning the range of collision probabilities with other fixed objects.

These greater inconsistencies are likely more of a function of the definition or grouping of the “Objects struck” than reduced collision probabilities in the geography or time period covered by the data.

Figure 26 addresses non-collision incidents that could damage a heavy truck and its payload. As shown in **Table 33**, The NUREG/CR-6672 and Lloyd’s Register studies considered only fire/explosions and “other” non-collisions.

The Modal Study and the current NWMO report included rollover and jackknife collisions as a subset of other non-collision collisions. All three previous studies generally align with the findings from the current NWMO report when combining “Other non-collision” and “Rollover/Jackknife” incidents.

Figure 24: Benchmarking Heavy Truck Collision Probabilities with Non-fixed Objects

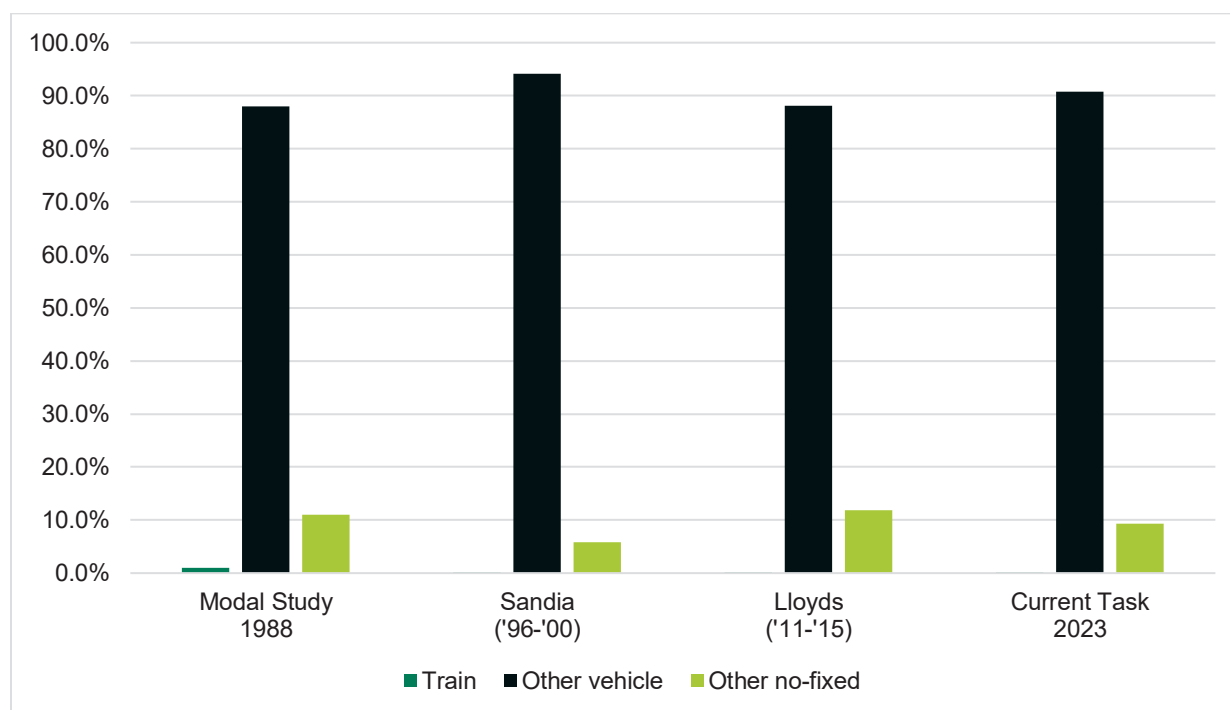


Figure 25: Benchmarking Heavy Truck Collision Probabilities with Fixed Objects

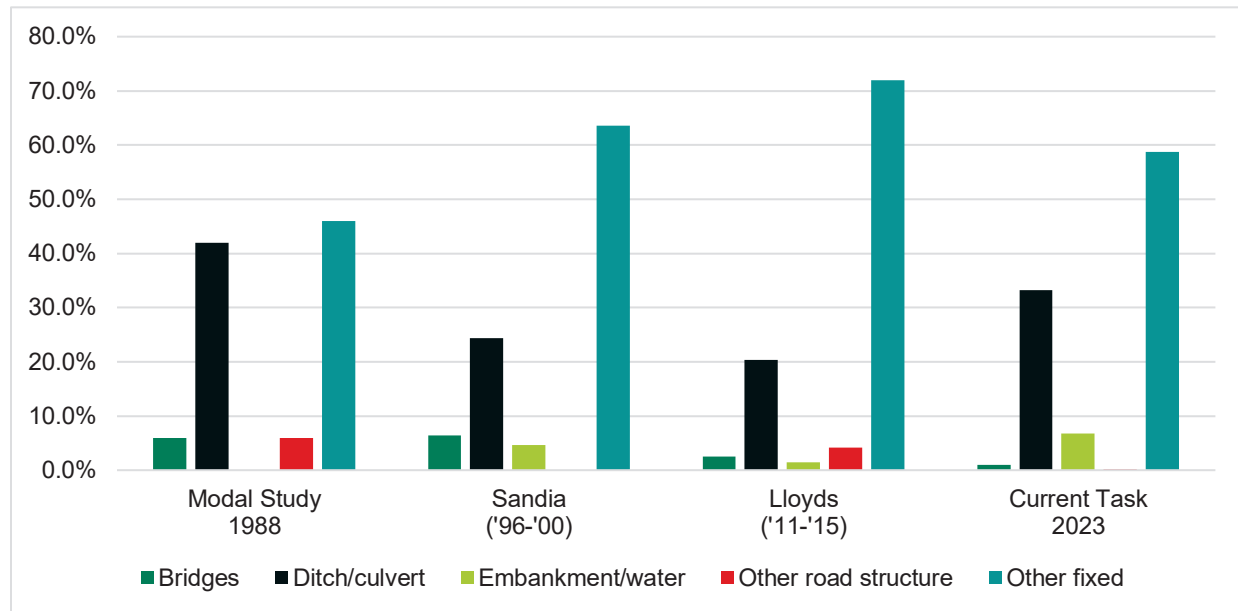
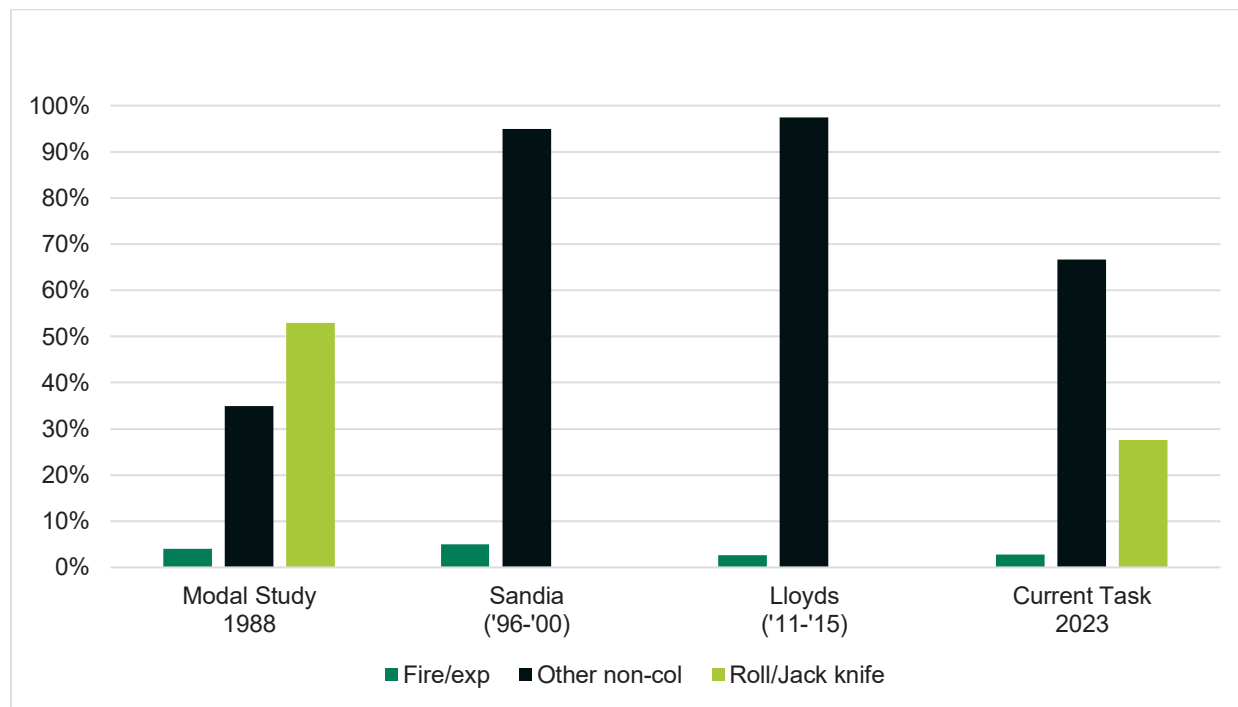


Figure 26: Benchmarking Heavy Truck Non-collision Collision Probabilities



From the comparisons provided in **Figure 24** through **Figure 26**, the heavy truck collision analysis presented in this report provides similar results to benchmarking studies in other reports. This demonstrates that heavy truck collision event causes and outcome probabilities in Ontario are similar to those in the U.S. and all of Canada.

11.2 Benchmarking for Rail Transportation

Previous reports were not found to provide meaningful benchmarks for rail transportation beyond the initial event tree branch of derailment and non-derailment. The current report considered a derailment probability of 63% and a non-derailment probability of 37% following a collision.

Appendix E of NUREG/CR-2125 [8] references a 2006 draft report from the Volpe National Transportation Systems Center, “Spent Nuclear Fuel Transportation Risk” [25]. This report provided a derailment probability of 73.6% and a non-derailment probability of 26.4% following a collision [25]. The derailment and non-derailment probabilities provided in the Volpe Center report are generally consistent with the Canadian data showcased in this report.

11.3 Benchmarking Conventional and TDG, Class 7, & Type B Shipments

The benchmarking described in the previous section considers conventional conveyances capable of transporting Type B packages but was not limited to any actual material transported. However, there is interest in understanding the differences in the safety record, if any, between different types of shipments such as conventional, Dangerous Goods (Class 7 materials specifically), and Type B packages. If there are differences, one should consider the catalyst for these difference (e.g., more stringent regulations).

Collision probabilities per shipment of Dangerous Goods or Class 7 materials in Canada have not been compiled by applicable agencies and only the total number of incidents are reported. As shown in **Table 4**, **Table 6**, and **Table 9**, the numbers of incidents in Ontario, Quebec, and New Brunswick for Dangerous Goods and Class 7 materials are small, but incident rates or probabilities are needed to draw comparisons against different shipment types and shipments in other countries. Therefore, the province-specific number of incidents cannot be benchmarked against other data sets or other data points.

For safety record benchmarking, data on the total kilometers travelled by conveyances carrying each type of good in a geographic region and time span, along with accident data, outcomes, and causal factors would be needed to conduct comparative assessments. However, while specific benchmarking of multiple studies of Dangerous Goods (total), Class 7 materials, and Type B shipments collision probabilities is not feasible at this time, a demonstration of the low numbers of incidents involving Type B shipments in Canada and worldwide is provided in the following paragraphs.

As described in **Section 5.1.5 Canadian Nuclear Safety Commission Data**, 492 radioactive material (Class 7) transportation incidents were reported to the CNSC between 2000 and 2022. Out of these, 58 incidents involved Type B transportation packages, of which none involved a loss of contents. While it was not possible to draw out specific conditional probabilities from the CNSC data, it further exemplifies the safety record of Type B shipments. However, this safety record also means that there is insufficient data on which to base statistical analyses for collisions involving conveyances transporting Type B packages alone.

The U.S. Department of Energy produced a study involving the history of worldwide used fuel transportation [12]. This study concluded that transportation of used fuel has been accomplished routinely and safely in many countries around the world for decades. It reported that, historically, collisions have been infrequent in used fuel and high-level radioactive waste transportation, and that when collisions have occurred, most have been minor collisions such as low-speed derailments or minor traffic accidents with little or no damage to the package being transported.

Specifically, the study showed that at least 25,400 shipments of used fuel were made worldwide between 1962 and 2016, and that all of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported. The worldwide number of Type B package shipments is far greater than used fuel shipments (e.g., approximately 255,000 shipments from 1979 through 1982) and were seen to feature a similar safety record.

12 Summary of Findings and Future Considerations

The literature review provided in this report confirms that truck and rail collisions involving radioactive materials and Type B packages are rare. Furthermore, not only are the worldwide number of shipments of Type B packages low, but only a few collisions involving shipments of Type B packages have ever occurred.

Finally, construction standards supported by collision and drop testing indicate that even in the event of a severe collision, a release of radioactive materials is unlikely. Therefore, the radiological risk of transporting Type B packages in compliance with transportation regulations is very low.

The analysis presented in this report also demonstrates that conventional truck/train collisions statistics must be used to construct a data set with a population size sufficient to draw meaningful conclusions on collision probabilities, causal factors, and accident severity.

The road collision datasets included in this analysis are sufficiently large and the resulting collision probabilities and causal factors map well against previous analysis carried out in Canada as well as internationally. Based on the statistical power of the large data sets, conclusions regarding collision causal factors are reliable enough on which to base future mitigation and control measures.

The predominant causal factors are being analyzed for a future mitigation report that will examine:

1. How the probability of a collision involving the transport of a Type B package can be reduced, and;
2. How the severity of an accident involving the transport of a Type B package can be mitigated.

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Appendix A

Conditional Probabilities for Incidents Involving Truck Tractors

Collision	Collision Type	Average probability (%)	Std. Dev.	Upper Bound Probability	Object Struck	Average probability (%)	Std. Dev.	Upper Bound Probability	Collision Configuration	Average probability (%)	Std. Dev.	Upper Bound Probability	Type of Shipment	Average probability (%)	Std. Dev.	Upper Bound Probability	Vehicle Severity Damage	Average probability (%)	Std. Dev.	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability	Ranking	
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	33.3%	58%	91.1%	4.99E-08	7.22E-07	111
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	66.7%	58%	124.4%	9.98E-08	9.86E-07	107
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	33.3%	58%	91.1%	1.93E-05	1.45E-04	72
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	66.7%	58%	124.4%	3.86E-05	1.97E-04	63
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	2.7%	0%	3.1%	4.14E-05	9.83E-05	61
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	22.0%	2%	24.0%	3.41E-04	7.66E-04	41
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	75.3%	2%	77.6%	1.17E-03	2.47E-03	33
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	2.7%	0%	3.1%	1.60E-02	1.97E-02	12
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	22.0%	2%	24.0%	1.13E-01	1.54E-01	2
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	75.3%	2%	77.6%	4.52E-01	4.95E-01	1
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	14.3%	38%	52.1%	7.10E-08	1.00E-06	110
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	57.1%	53%	110.6%	2.84E-07	2.13E-06	102
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	28.6%	49%	77.4%	1.42E-07	1.49E-06	106
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	14.3%	38%	52.1%	2.75E-05	2.01E-04	70
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	57.1%	53%	110.6%	1.10E-04	4.27E-04	48
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	28.6%	49%	77.4%	5.49E-05	2.99E-04	58
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	2.1%	2%	3.8%	1.07E-06	7.93E-06	96
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	36.3%	17%	53.7%	1.85E-05	1.12E-04	74
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	61.6%	17%	78.2%	3.14E-05	1.64E-04	64
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	2.1%	2%	3.8%	4.15E-04	1.59E-03	40
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	36.3%	17%	53.7%	7.17E-03	2.25E-02	20
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	61.6%	17%	78.2%	1.22E-02	3.28E-02	16
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	1.2%	2%	2.7%	1.24E-06	9.69E-06	94
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	54.4%	6%	60.4%	5.85E-05	2.19E-04	56
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	44.5%	6%	50.5%	4.78E-05	1.82E-04	59
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	1.2%	2%	2.7%	4.81E-04	1.94E-03	38
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	54.4%	6%	60.4%	2.26E-02	4.38E-02	8
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	44.5%	6%	50.5%	1.85E-02	3.66E-02	10
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	25.0%	41.8%	66.8%	4.15E-08	6.91E-07	112	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	49.2%	107.5%	166.8%	9.68E-08	1.51E-06	100	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	16.7%	40.8%	57.5%	2.77E-08	5.94E-07	113	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	25.0%	41.8%	66.8%	1.61E-05	1.38E-04	75	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	58.3%	49.2%	107.5%	3.75E-05	2.23E-04	65	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	16.7%	40.8%	57.5%	1.07E-05	1.19E-04	77	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	8.8%	5.2%	14.0%	3.48E-07	1.70E-06	100	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	35.6%	20.6%	52.4%	1.41E-06	6.85E-06	93	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	55.6%	5.2%	60.7%	2.20E-06	7.39E-06	91	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	8.8%	5.2%	14.0%	1.35E-04	3.41E-04	46	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	35.6%	20.6%	56.3%	5.45E-04	1.37E-03	37	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	55.6%	5.2%	60.7%	8.49E-04	1.48E-03	35	
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	71.9%	41%	112.9%	5.25E-07	9.12E-06	99
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	28.1%	41%	69.2%	2.06E-07	1.91E-06	103
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	71.9%	41%	112.9%	2.03E-04	6.26E-04	44
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	28.1%	41%	69.2%	7.95E-05	3.83E-04	51
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	15.0%	3%	17.6%	3.49E-05	8.72E-05	66
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	45.5%	3%	48.9%	1.06E-04	2.44E-04	49
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%	100.0%	100.0%	0.3%	0.2%	0.50%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	39.6%	4%	43.8%	9.23E-05	2.19E-04	50
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%	100.0%	100.0%	99.7%	0.2%	99.98%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	15.0%	3%	17.6%	1.35E-02	1.76E-02	14
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%	100.0%	100.0%	99.7%	0.2%	99.98											

Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	6.3%	13%	18.8%	7.51E-06	6.60E-05	78
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	17.2%	4%	21.1%	2.27E-05	6.15E-05	71
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	58.2%	5%	63.7%	7.69E-05	1.86E-04	52
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	24.6%	3%	27.9%	3.25E-05	8.15E-05	67
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	17.2%	4%	21.1%	8.77E-03	1.23E-02	18
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	58.2%	5%	63.7%	2.97E-02	3.72E-02	6
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	24.6%	3%	27.9%	1.26E-02	1.63E-02	15
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	52.3%	12%	63.9%	5.90E-06	2.18E-05	82
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	33.6%	10%	43.3%	3.81E-06	1.47E-05	89
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	14.1%	8%	22.0%	1.60E-06	7.48E-06	92
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	52.3%	12%	63.9%	2.29E-03	4.36E-03	25
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	33.6%	10%	43.3%	1.47E-03	2.95E-03	32
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	14.1%	8%	22.0%	6.18E-04	1.50E-03	36
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	19.4%	7%	26.2%	2.22E-06	8.40E-06	90
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	42.0%	7%	48.9%	4.79E-06	1.56E-05	85
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	38.6%	8%	46.2%	4.41E-06	1.48E-05	86
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	19.4%	7%	26.2%	8.58E-04	1.68E-03	34
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	42.0%	7%	48.9%	1.85E-03	3.11E-03	28
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	38.6%	8%	46.2%	1.71E-03	2.96E-03	29
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	16.7%	4%	20.2%	4.53E-05	1.24E-04	60
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	56.1%	4%	59.7%	1.53E-04	3.67E-04	45
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	27.2%	2%	29.3%	7.41E-05	1.80E-04	54
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	16.7%	4%	20.2%	1.75E-02	2.49E-02	11
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	56.1%	4%	59.7%	5.90E-02	7.35E-02	3
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	27.2%	2%	29.3%	2.87E-02	3.60E-02	7
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	36.1%	4%	40.5%	1.89E-05	5.41E-05	73
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	56.4%	7%	63.2%	2.95E-05	8.43E-05	69
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	7.5%	3%	10.4%	3.91E-06	1.39E-05	88
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	36.1%	4%	40.5%	7.32E-03	1.08E-02	19
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	56.4%	7%	63.2%	1.14E-02	1.69E-02	17
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	7.5%	3%	10.4%	1.51E-03	2.78E-03	31
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	11.2%	3%	13.8%	7.00E-06	2.28E-05	80
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	65.5%	6%	71.3%	4.09E-05	1.18E-04	62
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	23.3%	5%	27.8%	1.45E-05	4.60E-05	76
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	11.2%	3%	13.8%	2.71E-03	4.56E-03	23
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	65.5%	6%	71.3%	1.58E-02	2.37E-02	13
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%	100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	23.3%	5%	27.8%	5.62E-03	9.22E-03	21
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	1.3%	1%	2.3%	8.23E-07	4.92E-06	97
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	6.8%	5%	11.9%	4.20E-06	2.59E-05	87
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	91.9%	6%	97.5%	5.69E-05	2.13E-04	57
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	1.3%	1%	2.3%	3.38E-04	9.86E-04	42
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	6.8%	5%	11.9%	1.62E-03	5.18E-03	30
Truck Collision	Other Event	2.4%	2.0%	4.4%					100.0%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	91.9%	6%	97.5%	2.20E-02	4.26E-02	9

Appendix B

Conditional Probabilities for Incidents Involving Trains

Collision	Derailment Scenario	Average probability (%)	Std. Dev.	Upper Bound Probability	Collision Scenario	Average probability (%)	Std. Dev.	Upper Bound Probability	Type of Shipment	Average probability (%)	Std. Dev.	Upper Bound Probability	Breach of Dangerous Goods	Average probability (%)	Std. Dev.	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability	Ranking
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	6.86E-03	9.21E-03	13
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	4.81E-02	5.80E-02	6
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	8.90E-03	1.24E-02	12
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	6.23E-02	7.78E-02	4
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	1.2%	2.0%	3.1%	3.02E-04	1.05E-03	19
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Dangerous goods	12.5%	1.7%	14.2%	No breach	98.8%	2.0%	100.8%	2.59E-02	3.35E-02	9
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	1.83E-01	2.09E-01	2
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.3%	1.0%	1.3%	1.22E-05	9.43E-05	23
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.7%	1.0%	100.7%	3.88E-03	7.30E-03	15
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	2.72E-02	4.56E-02	8
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.1%	0.3%	0.5%	6.88E-06	2.80E-05	25
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.9%	0.3%	100.2%	4.73E-03	6.19E-03	14
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	3.31E-02	3.89E-02	7
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	3.30E-05	1.00E-04	22
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	2.31E-04	6.29E-04	20
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.2%	0.4%	0.5%	4.68E-06	2.01E-05	26
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.8%	0.4%	100.2%	2.68E-03	3.69E-03	16
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	1.88E-02	2.31E-02	10
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	1.04E-05	5.02E-05	24
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	7.27E-05	3.15E-04	21
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	2.9%	3.2%	6.1%	3.03E-04	8.68E-04	18
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Dangerous goods	12.5%	1.7%	14.2%	No breach	97.1%	3.2%	100.3%	1.00E-02	1.42E-02	11
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	7.22E-02	8.87E-02	3
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.6%	0.7%	1.3%	3.47E-04	9.23E-04	17
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.4%	0.7%	100.1%	6.11E-02	7.38E-02	5
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	4.30E-01	4.63E-01	1

Appendix F – Transportation Collision Mitigation Report

Title: <i>UFTS Transportation Collision Mitigation Report</i>		External Document No.: TDP 130 06 001	Revision: 000
Company Name: <i>AECOM Canada Nuclear Services Ltd., Nuclear Transport Solutions</i>			
NWMO Document No.: APM-REP-04240-0202	Revision: 000	NWMO P.O. No.: 2001513	
Date Submitted: <i>2023/10/31</i>		Page: <i>Approval Cover Sheet</i>	

Used Fuel Transportation System – Transportation Collision Mitigation Report

NWMO Authorization

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NWMO Used Fuel Transportation System Transportation Collision Data & Mitigation Assessment

Transportation Collision Mitigation Report

October 2023



Revision		Prepared	Checked/Approved
Final Report	Signature:	<i>George P Burnett</i>	<i>Daniel Fisher</i>
	Print Name:	George P Burnett	Daniel Fisher
	Date:	27 October 2023	27 October 2023

Signature in the above signatory box confirms that the parties have read, understood, and are committed to comply with the NTS Quality Plan requirements on behalf of their respective organisation, and that NTS and DRS hereby agree to provide all relevant requested documentation during an audit, should one be required by NWMO or its programme reviewers.

Issue:	1	2	3	4	5	6	7	8	9	10
Date:	See Authorisation Date									

AMENDMENT RECORD

#	Date	Details of Amendment
1	-	Original publication of Table of Contents
2	May 17, 2023	85% report
3	July 13, 2023	90% (Draft Report) incorporating comments and requests at 85% report review.
4	Aug 31, 2023	Draft report submission incorporating comments from NWMO and including executive summary.
5	Oct 10, 2023	Amendments throughout in response to AECOM and NWMO commentary.
6	Oct 27, 2023	Final Submission

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List of Acronyms and Abbreviations

ACC	Adaptive Cruise Control	ISO	International Organization for Standardization
ACT	Accident Conditions of Transport	LGV	Large Goods Vehicle
ACNS	AECOM Canada Nuclear Services	LKA	Lane Keeping Assist
ADAS	Advanced Driver Assistance Systems	M&TE	Measurement and Test Equipment
AECL	Atomic Energy of Canada Limited	MOD	Ministry of Defence (UK)
APM	Adaptive Phased Management	MTO	Ministry of Transport Ontario
AWS	Automatic Warning System	NCT	Normal Conditions of Transport
BSI	British Standards Institution	NDA	Nuclear Decommissioning Authority
CANUTEC	Canadian Transport Emergency Centre	NSC	National Safety Code Standard
CCMTA	Canadian Council of Motor Transport Administrators	NSR	Nuclear Security Regulations
CDM	Construction Design and Management	NTS	Nuclear Transport Solutions
CDP	Competency Development Plan	NWMO	Nuclear Waste Management Organization
CMS	Competency Management System	OTDR	On Train Data Recorder / Event Recorder
CNL	Canadian Nuclear Laboratories	PPE	Personal Protective Equipment
CNSC	Canadian Nuclear Safety Commission	PPM	Planned Preventative Maintenance
COSHH	Controlled Substances Hazardous to Health	PTNSR	Packaging and Transport of Nuclear Substances Regulations
CTA	Canadian Trucking Alliance	RACI	Responsible, Accountable, Consulted, Informed
CVSA	Commercial Vehicle Safety Alliance	SAE	Society of Automotive Engineers
DGR	Deep Geological Repository	SPAD	Signal Passed at Danger
DRS	Direct Rail Services	SPM	Safety Performance Monitoring Reporting
DSD	Deadman's Switch Device	STS	Secured Transportation Services
ECM	Entities in Charge of Maintenance	TCC	Transportation Command Centre
ECTS	European Train Control System	TPWS	Train Protection Warning System
GPS	Global Positioning System	TSB	Transportation Safety Board of Canada
GSM-R	Global System for Mobile Communications-Railway	TSP	Transportation Security Plan
HGV	Heavy Goods Vehicle	VMI	Vehicle Maintenance Instruction
IAEA	International Atomic Energy Agency	VIBT	Vehicle Inspection and Brake Test

Terms and Definitions

Collision	An unexpected and unintentional event that results in damage or injury. For this report, the event involves a large truck or train, resulting in subsequent “collision” and “non-collision” events.
Collision with a fixed object	Encompasses collisions with fixed objects, such as bridges, structures, trees, guide rails, rocks, ditches, etc.
Collision with a non-fixed object	Encompasses collisions with moving objects, such as another vehicle, trains, animals, pedestrians, cyclists, etc.
Heavy Goods Vehicle	A transport truck/trailer with a gross combined weight of 3,500 kg, including cargo (European Union), also known as a large goods vehicle (LGV).
Motor Vehicle Accident	A motor vehicle accident is an accident that involves a collision with another motor vehicle(s) (as defined in Canadian Nuclear Safety Commission Data).
Train Accident (Collision)	Train accident is an event in which the involved train collides with other objects (e.g., other trains, vehicles, fixed objects, lifeforms), derails, catches fire or explodes (as defined in Transportation Safety Board Data).
Train Derailment	Any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to track or equipment.
Type B Package	Type B packages are used to transport materials with high levels of radioactivity, such as used nuclear fuel, high-level radioactive waste, or high-radiation sources. These packages are typically large and heavy, designed and tested to provide adequate containment and shielding when subjected to normal conditions of transport and under hypothetical accident conditions set forth in regulations (i.e., pass stringent impact, drop, and puncture tests, an engulfing fire test, and immersion in water). In Canada, these packages are certified by CNSC.
Used Nuclear Fuel	Used fuel assemblies removed from a reactor after several years of use. The fuel is a solid material in the form of ceramic pellets contained within tubes made of corrosion-resistant zircaloy.

Executive Summary

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. NWMO's plan calls for used nuclear fuel to be safely contained and isolated in a deep geological repository (DGR), consistent with international practice. Currently, two candidate communities are being considered to host the DGR. One is in the Wabigoon Lake Ojibway Nation-Ignace area in Northwestern Ontario, and the second is in the Saugeen Ojibway Nation-South Bruce area in Southern Ontario. A final decision regarding the site for the DGR is expected by the end of 2024.

The transportation of used nuclear fuel from interim storage facilities located in Ontario, Quebec, and New Brunswick to the centralized DGR location will be required.¹ However, while there is a strong international track record regarding the shipment of radioactive materials, these shipments understandably raise concerns and queries from the public and interested parties regarding potential incidents or collisions during transport.

In 2022, NWMO commissioned a study aimed at gathering, analysing and assessing available collision data relevant to the modes (road and rail) and types of conveyances proposed to transport used fuel to the DGR in Type B Packages². This study, the Transportation Collision Data Analysis Report [1], conducted statistical analysis on types of collisions, severities, and potential causal factors in order to quantify transport collision probabilities with the intent that the collision probabilities, patterns, and trends identified therein would be used as input to future analyses.

In turn, this report aims to utilize the information developed previously, in combination with the first-hand operational experience provided by Nuclear Transport Solutions (NTS) in collaboration with Secured Transport Services (STS), to provide insights and inform the discussion into mitigation measures associated with safety during transport of used nuclear fuel.

As part of the United Kingdom's Nuclear Decommissioning Authority, NTS is responsible for safely transporting nuclear materials between Nuclear Decommissioning Authority (NDA) sites, primarily by rail and ship, as well as providing key operational solutions on both UK and international radioactive material transport. STS has extensive experience in transporting radioactive materials in North America, backed by decades of experience, including over 200 nuclear road transport operations in Canada.

This report intends to provide an overview of key findings from the Transportation Collision Data Analysis Report with regard to the most probable types of collisions that conveyances meant to transport used nuclear fuel may encounter during both road and rail shipping operations. Leveraging the operational experience of both NTS and STS, this report then provides an overview of road and rail operations and identifies potential mitigation measures that can be implemented by the NWMO in their used fuel transportation program.

¹ Used fuel from Whiteshell Laboratories (Manitoba) is anticipated to be consolidated at Canadian Nuclear Laboratories (Ontario) prior to the start of NWMO transportation operations.

² Type B packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions such as drops, fires, and immersion in water. Type B packages are commonly used to transport used nuclear fuel by road, rail, and water modes of transport.

Furthermore, this report provides insights into the aspects of nuclear material transportation that differentiate it from commercial road and rail shipments with regard to overall safety and security, as well as incident response. This includes, but is not limited to:

- Route Planning/Reconnaissance
- Driver Training
- Advanced Driver Assistance Systems
- Vehicle Maintenance and Inspection
- Driver Condition / Fitness for Duty
- Adverse Weather Considerations
- Road Surface Conditions
- Train Safety Features
- Informed Decision Making
- Emergency Response
- Incident Drills and Exercises
- Transportation Command Center
- Human Performance Programs
- Risk Management
- Audits
- Asset Maintenance and Inspections
- Personnel and Operational Safety
- Supplier and Contract Management

1 Introduction

1.1 Background

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. Canada's plan for managing used nuclear fuel is known as Adaptive Phased Management (APM). It consists of isolating and containing used nuclear fuel in a Deep Geological Repository (DGR) using a multiple barrier system in a robust host geology.

Canada's used nuclear fuel is currently safely stored on an interim basis in licensed facilities at reactor sites in Ontario, Québec, and New Brunswick, as well as at Atomic Energy of Canada Limited's (AECL) nuclear research laboratories in Ontario and Manitoba. Managing all of Canada's used nuclear fuel in a single repository location will require the transport of used nuclear fuel from these interim storage facilities to the centralized DGR location.

NWMO is currently in the process of identifying a willing and informed host community and region for the APM DGR. The Township of Ignace and Wabigoon Lake Ojibway Nation in Northwestern Ontario and the Municipality of South Bruce and Saugeen Ojibway Nation in Southern Ontario are potential host areas for the project. Site selection is currently expected to occur in late 2024. The interim storage sites and candidate DGR sites are outlined in

Figure 1.

Figure 1 Overview of Existing Interim Storage and Candidate DGR Sites



NWMO's responsibility in used nuclear fuel management includes designing and developing a transportation system for the safe and secure delivery of used fuel from current interim storage facilities to the DGR. Current plans are to begin operation of a repository facility no sooner than 2043. Once a facility is constructed and licensed, used fuel will be transported from the existing interim storage sites to the repository by road and/or by rail.

The objective of this report is to take the key findings from the Transportation Collision Data Analysis Report and identify potential mitigating measures that can be implemented by NWMO in their used fuel transportation program to reduce the likelihood of transportation collisions with consideration of the types of modes and conveyances being studied by NWMO.

The information in this report is presented to provide potential mitigations to prevent accidental collisions or derailment scenarios for NWMO's program of transport.

1.1.1 Radioactive Material Transportation

The transportation of radioactive materials in Canada is governed by jointly by the Canadian Nuclear Safety Commission (CNSC) and Transport Canada under several pieces of legislation, including but not limited to the Transportation of Dangerous Goods Act (S.C. 1992, c. 34), the Packaging and Transport of Nuclear Substances Regulations (PTNSR) (SOR/2015-145) [2], the Nuclear Safety and Control Act (S.C. 1997, c.9) [3], and the Nuclear Security Regulations (NSR) (SOR/2000-209) [4].

Under the framework set out by the above-noted legislation, radioactive materials are defined as Class 7 Dangerous Goods and can be further categorized according to their specific properties pertaining to the type and level of ionizing radiation that may be applicable. Thousands of shipments of radioactive materials are safely carried out within Canada annually by various industries, including power production, surveying, and nuclear medicine.

Drawing from the International Atomic Energy Agency's Regulations for the Safe Transport of Radioactive Materials (IAEA, SSR-6) [5], Canada's PTNSR sets out requirements for the types of packages that must be used to transport various categories of radioactive materials.

This includes the content characteristics and the safety-related performance of packages during Normal Conditions of Transport (NCT) and Accident Conditions of Transport (ACT). Different categories of packages may be required depending on the nature and form of the content. These include but are not limited to, the three types summarised in **Table 1**.

Table 1 Categories of Transportation Packages

Type IP Packages	Type A Packages	Type B Packages
These packages are utilized for shipping materials considered to pose a low risk or hazard due to the nature and level of the contents (low specific activity or surface contamination). They provide a basic level of protection and shielding and must withstand normal transport conditions, among other requirements. Common contents include surface-contaminated clothing or PPE.	These packages are designed for the transport of moderately radioactive materials. They provide a higher level of protection compared to Type IP packages. They are rated to contain levels of ionizing radiation below a given threshold value (known as an A2 value) which varies depending on the nature of the contents. Common contents found in Type A packages include radiopharmaceuticals and other industrial materials.	These packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions. Type B packages are commonly used to transport used nuclear fuel.

Note: The A₂ value is the maximum amount of radioactivity of a specific radioisotope measured in terabecquerel (TBq) than can be transported in a Type A package for normal form materials like most radioactive waste. In other words, the amount of radioactivity they contain is limited by regulations and in the event of a release, these limits ensure that the risk from radiation/contamination is managed.

Safety of Type B Transport Packages for Used Nuclear Fuel

The basic philosophy behind the Canadian transport regulations is that safety heavily relies on the design of the transport package. Used fuel packages, or Type B packages are designed, tested, and certified to retain their contents during normal operations and in the event of a credible accident. Under the regulations, the package design must meet a series of rigorous impact, fire, and water immersion tests:

- Two drop tests: 1) a 9 meter drop onto an unyielding surface and 2) a 1 metre drop onto a steel bar at least 20 centimeters long; conducted in the sequence and orientation that would result in the most damage to the package.
- Following the drop tests, a fire test on the same specimen which the package is subjected to a fully engulfing fire of 800°C for 30 minutes.
- Immersion test where the cask is then subjected to conditions equivalent to 15 metre submersion for 8 hours. For casks designed for the more highly radioactive materials there is an enhanced immersion test of 200 metres for 1 hour.

These tests ensure that packages can withstand accidents involving crashes, fires, or submergence under water that can realistically be envisioned.

1.1.2 Type B Transportation Packages and Conveyances

NWMO is currently assessing several conveyance options for transporting various Type B transport packages from interim storage sites to the APM DGR. Types of conveyances being considered include the:

- Truck tractor (see **Figure 2**)
- Rail consist (see **Figure 3** for an image of the rail consists and **Figure 4** for an image of the 8-axle DSC-TP railcar)
- Heavy haul truck (super-load truck)³

A heavy haul truck was scoped out of NWMO Transportation Collision Data Analysis Report [1] due to a lack of databases containing collision information on these types of conveyances, therefore the focus of that report was on truck tractors and rail consists. This assumption was carried forward into this report.

Depending on the final mode chosen and the storage method utilized at the interim storage sites, these conveyances may transport various Type B transportation packages (i.e., the Used Fuel Transportation Package, the Dry Storage Container Transportation Package, the Basket Transportation Package).

Figure 2 An Illustration of Road Conveyance with Used Fuel Transportation Package (top) and Basket Transportation Package (bottom)

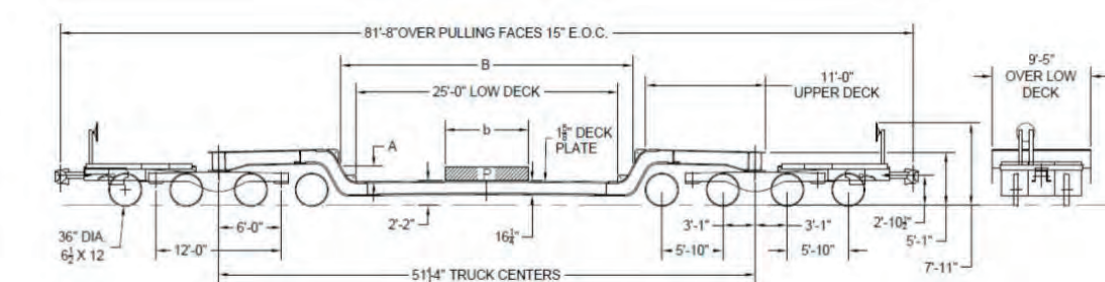


³ Heavy haul truck has been scoped out of this report because there were no databases containing collision information on these types of conveyances, therefore the focus of this report is on truck tractors and rail consists.

Figure 3 An illustration of Dry Storage Container Transportation Packages and Supporting Rail Consist



Figure 4 An illustration of the 8-axle Dry Storage Container Transportation Package Railcar



1.2 Objective of the Report

The Transportation Collision Mitigation Report was prepared by Nuclear Transport Solutions (NTS) for NWMO's use in addressing the specific needs of the project and their business. This report is based on available information at the time of preparation.

The purpose of this report is to leverage the statistical analysis and assessment of the accident data developed in the Transportation Collision Data Analysis Report [1] to identify potential collision mitigation methods that can be implemented within NWMO's transportation program (including conveyance, equipment inspection, maintenance, and operational and administrative controls).

To meet the overall project objectives, the scope of work has been organized into three distinct and integrated Work Packages which focus on the following:

- Work Package # I: Collection and analysis of existing relevant collision data,
- Work Package # II: Development of event trees and collision probabilities, and,
- Work Package # III: Identification & assessment of mitigation measures that can reduce risks.

The Transportation Collision Data Analysis Report [1] addresses Work Package #I and Work Package # II; analysing historical collision conditions to quantify collision probabilities which may apply to road and rail conveyances which are being considered by NWMO for transporting Type B Packages. **Section 1.4** provides a summary of key conclusions of the Transportation Collision Data Analysis Report [1] which were used to inform this report.

This report encompasses the work completed in Work Package # III. The objective of this report is to take the key findings from the previous work packages and identify potential mitigating measures that can be implemented by NWMO in the used fuel transportation program to reduce the likelihood of a transportation accident with consideration to the types of modes and conveyances being studied by NWMO.

Nuclear Transport Solutions (NTS) worked in collaboration with AECOM Canada Nuclear Services (ACNS) to complete this third work package regarding transportation operational considerations for the safe transport of used fuel in Canada.

NTS is a wholly owned subsidiary of the United Kingdom's Nuclear Decommissioning Authority (NDA), with extensive and proven expertise in irradiated fuel management and nuclear material transportation. This report draws upon direct operational experience in strategic assessments and feasibility studies relating to irradiated fuel management and transportation.

In partnership with Secured Transportation Services (STS), NTS draws from its decades of nuclear transport experience to develop this report. A robust approach to a used fuel transportation system is proposed by mapping operational experience to the outcomes identified with the Transportation Collision Data Analysis Report [1].

1.3 Content Overview

This report encompasses the work completed in Work Package # III as described above.

Section 2:

Transport Overview

A high-level overview of the transport context, safety, design requirements, and testing of Type B packages.

Section 3:

Road Operations

Comparison of conventional trucking to nuclear transport highlighting safety considerations. This section covers key elements of safe nuclear transport by road.

Section 4:

Rail Operations

Discussion of key rail safety features, as informed by historical and operational experience.

Section 5:

Emergency Response and Transport Security Considerations

Overview of the incident/emergency response and transport security arrangements that accompany safe nuclear transport operations.

Section 6:

Human Performance Approach

Overview of management factors which comprise key programme elements associated with fitness for duty, performance programs, competency management and recruitment.

Section 7:

Key Management Aspects

Discussion of the key organizational and management factors that culminate to form a safe operating environment for nuclear transport.

Section 8:

Conclusions

A summary encompassing conclusions and recommendations of each section of the transport mitigation report.

1.4 Summary of Transportation Collision Data Analysis Report

As described in **Section 1.2**, this report leveraged the statistical analysis and assessment developed in the Transportation Collision Data Analysis Report [1] which collected and analysed Canadian transport collision datasets from 2010-2019 to identify the highest probability of accident scenarios (e.g., collision with fixed or non-fixed objects for road operations, collision leading to derailment for rail operations).

The nuclear transport industry is limited in probabilistic studies due to a lack of collision data for conveyances carrying Type B packages compared to conventional commercial transport operations or even transports of other classes of dangerous goods. While this can be interpreted as a properly functioning regulatory regime influencing operational safety, the distinct challenges for transporting nuclear material must still be considered in operational planning and preparation regardless of data availability.

Table 2 gives an overview of the scenario rankings found in the previous work packages [1]. These scenarios encompass the most probable collision types and objects struck following the advent of a collision taking place. A full listing of collision scenarios is available in the preceding work packages report [1]; see sections 9.1.2 for truck collisions and 9.2.2 for train collisions therein.

Table 2: Summary of scenario rankings from previous work packages.

Short-List of Ranking (Truck Tractor)		
Collision Type	Object Struck	Rank
Collision with a non-fixed object	Other moving vehicles (light damage to vehicle)	1
Collision with a non-fixed object	Other moving vehicles (severe/moderate damage to vehicle)	2
Non-collision	Other non-collision e.g., skidding/sliding or running off-road (severe/moderate damage to vehicle)	3
Collision with a fixed object	Other fixed objects e.g., tree, culvert, guide rail (severe/moderate damage to vehicle)	4
Collision with a fixed object	Other fixed object (light damage to vehicle)	5
Short-List of Ranking (Train)		
Derailment Scenario	Collision Scenario	Rank
Derailment	Non-main-track derailment (conventional shipment)	1
Remains on rail	Other objects e.g., abandoned vehicle, track unit (conventional shipment)	2
Derailment	Main-track train derailment (conventional shipment)	3
Remains on rail	Life form (conventional shipment)	4
Derailment	Non-main-track train derailment (dangerous goods)	5

The Transportation Collision Data Analysis Report [1] further breaks down observed collision scenarios per their probability of occurrence, associated vehicle damage severity (as applicable). It then goes on to analyse causal factors and emerging themes of interest for certain scenarios.

As part of this report, NTS and STS leverage decades of experience in the transport of nuclear material by road (STS has conducted over 200 nuclear road transport operations in Canada). This experience is used to provide guidance as it relates to mitigation measures associated with noted collision scenarios as well as other risks registered by both carriers. Similarly, NTS works to mitigate wider risks associated with rail transport, influenced by decades of operational experience and the UK's national rail safety group, including:

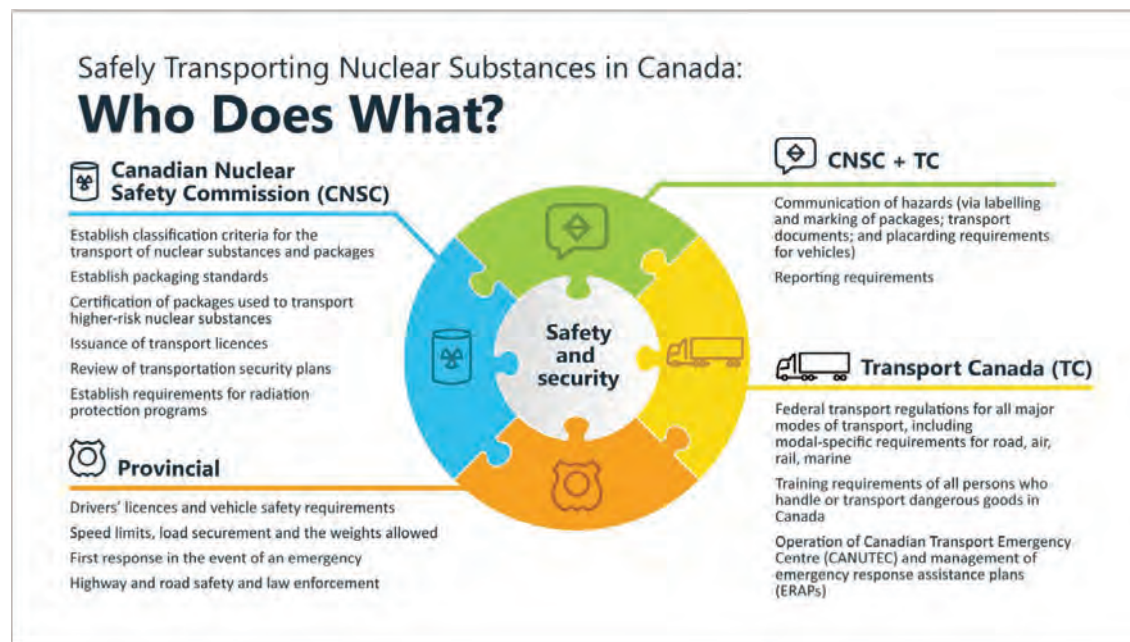
- Wagon Condition on the network
- Road Risk
- Workplace H&S Arrangements
- Safety Critical Communications
- Signal Passed at Danger (SPAD) Reduction
- Fatigue
- Trespass & Security
- Health & Wellbeing
- Common safe systems of Work

This report provides operational insight into mitigation measures that are in place for the identified transport accident scenarios while also providing a holistic view of the wider mitigating factors associated with nuclear transport operations.

2 Transport Overview

Canada has a robust regulatory framework governing the transport of nuclear material, as outlined within **Section 1.1.1**, which is overseen by the CNSC, Transport Canada and provinces. The transport safety requirements of the IAEA SSR-6 [5] are adopted through the CNSC's PTNSR [2], with the PTNSR serving to establish the safety requirements for the packaging and transport of nuclear substances. **Figure 5** provides an overview of the responsibilities associated with the safety and security of transporting nuclear substances in Canada.

Figure 5 Overview of shared regulatory oversight for transport of nuclear substances in Canada [6]



Transport Canada utilizes the Transportation of Dangerous Goods Regulations [7] to set transport requirements for the movement of radioactive material. In tandem, these regulations create a robust framework that must be complied with when packaging and transporting nuclear material in Canada.

When considering the transport of Type B packages (see **Table 1**), stringent testing requirements are required to ensure that transport safety is built into the design of the package. NCT testing sees packages undergo a water spray test, free drop test, stacking test and penetration test.

To ensure the robustness of Type B packages, ACT testing extends the requirements to demonstrate robustness in conditions deemed to be credible severe accident conditions; these include:

Mechanical Testing

Three different drop tests in an order such that, on completion of the mechanical testing, the package will have suffered the maximum damage prior to the thermal testing that follows. The drops include:

- (a) 9m drop test to suffer the maximum damage.
- (b) 1m drop onto punch bar rigidly mounted perpendicular to the target.
- (c) Dynamic crush test created by positioning the package in a manner that causes maximum damage from the drop of a 500kg mass from 9m.

Thermal Testing

The package is held under conditions of an ambient temperature of 38 °C and subjected to:

- (a) 30 minutes of a fully engulfing flame, at an average temperature of 800 °C
- (b) Exposure back to an ambient temperature of 38 °C

Water Immersion Test

The package is fully immersed under at least 15m of water for a period of no less than 8 hours in a manner that would cause maximum damage. For some sub-categories of Type B packages, an enhanced water test is required consisting of full immersion under at least 200m of water for no less than 1 hour.

Any package that can successfully maintain integrity throughout the ACT is, by design, developed to withstand transport accidents deemed credible and severe, and is inherently robust.

In developing mitigation measures for transport accidents, acknowledging the testing requirements and subsequent safety conscious design for Type B packages allows for a commensurate, yet robust approach to transport safety. Beyond this, data availability for transport accidents involving Type B packages is very limited as incidents involving these package types are particularly uncommon, with an event involving any form of radiological release being extremely rare. It is noted that the previous work packages have drawn from wider data sets of involving other heavy vehicles to obtain viable data sets.

3 Road Operations

Section 3 provides an overview of the key risks associated with the carriage of dangerous goods with a focus on class 7 radioactive material, comprising the factors that increase the likelihood of a collision with a fixed and non-fixed object, which have been identified as the most probable collision scenario within NWMO Transportation Collision Data Analysis Report [1] for road operations.

This section draws upon the established experience of nuclear road transport operations of STS and NTS management experience of road operations, to provide insight on best practice for safety.

3.1 High Level Comparison of Operating Conditions for Conventional and Nuclear Transports

It is recognized that many questions and concerns are raised regarding the transportation of used nuclear fuel based on the general public's understanding of the commercial trucking industry. For example, the Transportation Collision Data Analysis Report [1] Section 6.2.1.1 identified that collisions with non-fixed objects (such as other moving vehicles) was the leading collision type by sequence of events, followed by collisions with fixed objects.

However, the road transport of nuclear materials in Canada occurs in a **very different environment** from conventional trucking, in part due to the many additional safety requirements and enhanced training requirements:

- Truck drivers for nuclear shipments are not under pressure to achieve tight profit-driven delivery schedules, deadlines, or similar constraints requiring long hours at the wheel. The contingent risks of “driver error, speeding, and cutting corners” are often mitigated by the presence of security escorts, a higher standard of training and experience, operational controls, and a tighter regulatory environment than that which generally exists for standard commercial trucking – which is unconstrained by these factors.
- Transport of Category II nuclear material in Canada has a regulatory requirement that the shipment is conducted by qualified drivers with strict licenses and certifications for the transport and packages set out within the PTNSR [2] while adhering to wider transport regulatory requirements.
- Nuclear transport drivers are expected to ensure that they are implementing the Transportation Security Plan (TSP), performing routine communications check calls, logging calls received, etc.
- Operations typically see sensors attached to packages for vibration and drop detection and issue an alert to initiate the appropriate response.
- Drivers are also expected to meet the pre-identified transportation schedule which derives from the need for regulatory compliance for safety and security. As such, safety and security requirements take precedence over any time pressures that could be born of financial gain (as may be seen in commercial road operations). In practice this could see designated security checkpoints factored in and a detailed notification matrix developed to ensure communication of scheduling to operational support teams.

For all nuclear transport operations overseen by STS in Canada, assurances are provided that the truck drivers deployed are qualified, experienced, adequately rested, and familiar with the route plan, the TSP, the cargo vehicle and cargo, and the regulatory guidelines. These are all considered key elements in conducting nuclear road transport operations.

While it is not appropriate to say that equipment failure, stress, fatigue, or other general transportation environmental variables could not also occur for nuclear transports, it is important to note that the statistical probability of such risks must consider the **significant differences** between the nuclear transport operations and the standard commercial operations. Data derived from the standard commercial transportation industry would show a higher rate of collisions than would be applicable to the nuclear transportation industry.

Therefore, in comparison with the conditions for standard commercial trucking noted above, road transport of nuclear material in Canada is conducted under a rigorous regulatory framework.

3.2 Potential Causes and Mitigation Measures Associated with Truck-Tractor Collisions

As identified within the NWMO Transportation Collision Data Analysis Report [1], Table 11 details leading contributing factors associated with conventional truck-tractor collisions. The identified categories of contributing factors fall into 4 groups across the data analysed by the previous work packages, which are:

- Driver action
- Driver condition
- Weather condition
- Road surface condition

By leveraging the findings in [5], this section considers additional contributing factors (such as mechanical failures) and identifies relevant mitigating measures which can be incorporated in NWMO transportation program for road shipments. **Table 3** provides a mapping of the discussion as it relates to contributing factors and relevant potential mitigating measures for truck-tractor collisions.

Table 3: Truck-Tractor Collisions - Potential Causes and Mitigation Measures

Topic	Potential Causes	Potential Mitigation Measures
Driver Action (Section 3.3)	Potential Causes (Section 3.3.1)	Mitigation Measures (Section 3.3.2) • Route Planning and Route Reconnaissance • Driver Training • Advanced Driver Assistance Systems (ADAS) • Speed Reduction
Mechanical Failures (Section 3.4)	Potential Causes (Section 3.4.1)	Mitigation Measures (Section 3.4.2) • Vehicle Maintenance • Vehicle Inspection • Securing Loads
Driver Condition (Section 3.5)	Potential Causes (Section 3.5.1)	Mitigation Measures (Section 3.5.2) • Driver Fatigue • Driver Health • Driver Impairment • Inattentive Driving
Adverse Weather Conditions (Section 3.6)	Potential Causes (Section 3.6.1)	Mitigation Measures (Section 3.6.2) • Monitoring Weather Conditions
Road Surface Conditions (Section 3.7)	Potential Causes (Section 3.7.1)	Mitigation Measures (Section 3.7.2) • Monitoring Weather Conditions • Route Planning and Route Reconnaissance • Monitoring of Road Conditions from TCC

3.3 Driver Action

3.3.1 Potential Causes

As identified within the previous work packages [1], driver action, i.e., reckless driving and driver error, is the leading cause of conventional truck-tractor collisions.

- A driver may mishandle traffic or road conditions if unfamiliar with the highway.
- Any driver who does not pay attention to traffic or road conditions or follow highway traffic laws is at risk of causing an accident.
- Distracted driving (for example, driving while texting or talking on the phone) is a hazardous practice that puts drivers and other travellers in danger.

3.3.2 Potential Mitigation Measures

Potential mitigating measures related to reckless driving and driver error are described below and include route planning and route reconnaissance; driver training; Advanced Driver Assistance Systems (ADAS); and speed reduction, where appropriate.

Route Planning and Route Reconnaissance

Given that the transportation of dangerous goods by road requires careful planning and preparation, route planning is a vital element of the preparation process. Such a plan must be cognisant of the specific hazards associated with the dangerous goods in transport.

Route requirements for nuclear material are specifically designed to use prescribed roadways whenever possible and avoid unsuitable, narrow, or poorly maintained roads.

Industry best practices for developing a route plan for the carriage of dangerous goods by road are as follows:

- Identify the Route Restrictions - This includes identifying any restrictions on certain roads or highways, such as weight or size restrictions, and any associated time restrictions. Route planning should take specific note of road surfaces, seasonal variances and implications when cross-referenced with the transport arrangements proposed.
- Identify the Potential Hazards - Steep inclines, sharp curves, low bridges, and narrow roads could all be considered potential hazards on a road route.
- Consider the Transport Vehicle - This includes considering the size and weight of the vehicle, as well as the type of cargo being transported.
- Consider Emergency Response Procedures - Emergency response procedures should also be considered when developing a route plan for the carriage of dangerous goods by road. This includes identifying emergency response teams and procedures along the route and ensuring that all necessary contact information is readily available.

Unfamiliarity with the highway can be an issue early in a campaign or during a one-time shipment leading to driver error. However, this can be mitigated by developing detailed turn-by-turn directions for the drivers and security escorts via the route plan. This practice is enhanced by conducting “Route Reconnaissance”, another best practice in which a proposed route for transport of nuclear materials is driven in advance to check for low overpasses, narrow bridges or tunnels, steep grades, tight corners, bridges that have weight restrictions, and refuelling plazas large enough to accommodate nuclear transportation vehicles that also offer easy ingress and egress. This allows the Transportation Command Centre (TCC, see **Section 5.2**) to relay any specific hazards or guidance directly to the drivers and other operational support teams.

Driver Training

One of the most effective measures to reduce risks associated with reckless driving or driver error is training. Driver training should cover defensive driving techniques, safe loading and unloading practices, and emergency response procedures. In addition, it should also address the specific hazards associated with the dangerous goods being transported.

Industry best practices for driver training include a combination of classroom instruction and practical experience. In Canada, Transport Canada provides guidance on the legislation covering driver training courses for the transportation of dangerous goods [8]. The courses are accredited by Transport Canada and cover a range of topics, including the transportation of dangerous goods regulations, the properties of dangerous goods, and emergency response procedures. These courses are delivered by experienced instructors and provide participants with hands-on training in a range of scenarios.

In addition to formal driver training courses, ongoing education and training elements are critical components of driver training. Drivers should receive regular updates on changes to regulations governing the transportation of dangerous goods, as well as ongoing education on best practices for safe driving.

Operationally, drivers are expected to conduct routine communications such as check-calls which are typically streamlined by using a single button press to transmit “all is well” messages to the TCC to minimise distraction while communicating driver condition. This helps to further reduce the hazards of distracted driving.

Having security escort personnel accompanying the truck-tractor also acts to forestall careless or reckless behaviour as an additional layer of assurance. While accidents caused by other drivers are a possibility, nuclear transport operational protocols are designed to reduce the probability of any nuclear material transport driver behaving carelessly or recklessly at any time.

Advanced Driver Assistance Systems (ADAS)

ADAS are a collection of electronic systems and features designed to enhance vehicle safety and driver comfort by automating or enhancing certain driving tasks. These systems use various sensors, cameras, and onboard computing to provide real-time feedback and assistance to the driver, helping to prevent accidents and improve overall driving efficiency.

ADAS are increasingly being adopted by commercial goods vehicles in Canada to improve safety, efficiency, and overall driving experience. Some common ADAS technologies employed include adaptive cruise control, automatic emergency braking, lane departure warning, blind spot detection, and traffic sign recognition.

ADAS technologies can be categorized into five levels based on their degree of automation, as defined by the Society of Automotive Engineers (SAE) International [9].

Level 0	No Automation: The driver is fully responsible for all driving tasks without vehicle assistance. ADAS features in this level may include basic warnings and alerts, such as parking sensors, but do not actively control the vehicle.
Level 1	Driver Assistance: In this level, the vehicle can assist with either steering or acceleration/braking, but not both simultaneously. The driver remains in control of the vehicle and is responsible for all other driving tasks. Examples of Level 1 systems include Adaptive Cruise Control (ACC) and Lane Keeping Assist (LKA).
Level 2	Partial Automation: The vehicle can control both steering and acceleration/braking simultaneously under certain conditions, but the driver is still required to monitor the environment and take over control when needed. Examples of Level 2 systems include Tesla’s Autopilot and Volvo’s Pilot Assist.
Level 3	Conditional Automation: In this level, the vehicle can handle all aspects of driving under specific conditions, such as highway driving, but the driver must be ready to take over control when the system requires it. An example of Level 3 automation is Audi’s Traffic Jam Pilot.
Level 4	High Automation: The vehicle can handle all driving tasks without human intervention within a specific operational domain (such as geofenced areas or dedicated lanes). However, a human driver may still take over control when desired. Examples of Level 4 systems are currently being tested by companies like Waymo and Cruise.

Level 5 [Full Automation](#), where the vehicle can handle all driving tasks under all conditions without any human intervention. However, this level is not considered part of ADAS, as it represents a fully autonomous vehicle that does not require any driver assistance.

Transport Canada frequently promotes the use of ADAS in commercial vehicles to reduce accidents and improve road safety. In 2019 the Canadian Council of Motor Transport Administrators (CCMTA) released a report on the impact of ADAS on commercial vehicles, discussing their benefits, challenges, and recommendations for implementing such systems [10]. Further, the Canadian Trucking Alliance (CTA) has been advocating for ADAS adoption in the trucking industry. The CTA Blue Ribbon Task Force on the Driver Shortage published a report suggesting that adopting ADAS technologies can help address the driver shortage in the industry by making the job more attractive to potential drivers [11].

The following summary provides information on five key components of ADAS:

Duress Button	A duress button, also known as a panic button, is designed to help drivers in emergency situations. When pressed, it immediately sends a distress signal to a monitoring centre (the Transportation Command Centre (TCC) described in Section 5.2) or designated authorities. This feature is particularly useful in cases such as security events or medical emergencies. The signal can be transmitted via cellular networks or other communication technologies.
GPS Tracking System	Global Positioning System (GPS) tracking systems enable real-time location monitoring of vehicles, which can be crucial for fleet management, stolen vehicle recovery, and general navigation purposes. These systems use a combination of satellites and cellular networks to provide accurate and up-to-date positioning data. With the integration of ADAS, GPS tracking can also facilitate features like geofencing (creating virtual boundaries) and route optimization.
Anti-Theft Features	ADAS offers various anti-theft features to enhance vehicle security. These include immobilizers, which prevent unauthorized vehicle operation by disabling the engine or fuel system; alarms, which deter theft attempts through loud audible alerts; and remote monitoring and control systems, which allow owners to track their vehicles, lock/unlock doors, and even shut down engines remotely.
Event Recorders	Event recorders, also known as black boxes or crash data recorders, are devices that capture, and store data related to vehicle performance and driver behaviour. In the event of an accident, these recorders can provide valuable information for accident reconstruction and insurance claims. They typically collect data such as vehicle speed, braking activity, steering inputs, and impact forces.
Real-Time Metrics	Real-time metrics involve the collection and analysis of data from various sensors and systems within the vehicle. This data can include information about vehicle performance, driver behaviour, traffic conditions, and environmental factors. By analysing real-time metrics, ADAS can provide valuable insights to improve safety, optimize fuel efficiency, and enhance the overall driving experience.

Speed Reduction

Speed reduction is widely considered amongst the most easily implemented and effective traffic accident mitigation measures available; however, it is not mandated for nuclear transport operations. Reducing transport speeds has been shown in numerous studies to facilitate safety by increasing reaction time for drivers and generally reducing the distance required to execute emergency stops.

Drivers must also consider that slowing down the speed of nuclear transport vehicles will also slow down the speed of vehicles behind them and make it more difficult for other drivers to get around the slow-moving cargo vehicles. Therefore, drivers must use their own judgement in slowing, particularly in areas that have limited passing options for other vehicles, reinforcing the importance of high-level driver training.

3.4 Mechanical Failures

3.4.1 Potential Causes

Commercial truck-tractors accumulate wear and tear as they are driven through challenging weather and road conditions. If these risks are not carefully monitored, mechanical failures may occur, such as tire blowouts and engine trouble.

Truck-tractors can also create a serious hazard by incorrectly parking on the side of the road while attending to mechanical issues. Ill-maintained lighting standards and reflective markings can make a truck or its trailer difficult to be seen, placing the truck at risk of being hit by passing vehicles.

3.4.2 Potential Mitigation Measures

The risk of mechanical error places significant importance on the application of proper vehicle maintenance, inspection and load securing methods. Mitigation approaches from best practice and operational experience are as follows.

Vehicle Maintenance

Commercial cargo vehicles must comply with various Canadian standards and stay in good working order through regular maintenance. Commercial carriers are legally required to have an effective maintenance and inspection program. Additionally, trucks with a licensed mass of more than 11,794 kg must complete trip inspection reports and carry a schedule as set out under National Safety Code Standard 13 (NSC-13) [12].

The PTNSR stipulate that carriers must implement and maintain work procedures to ensure compliance with the Regulations and keep a record documenting those procedures [2]. Nuclear transport cargo trucks routinely undergo more in-depth inspections as part of established best practice to ensure they are unlikely to break down en route.

Vehicle maintenance is critical to ensuring road safety and preventing incidents during transportation. In Canada, the Canadian Council of Motor Transport Administrators (CCMTA) has established guidelines and standards for Heavy Goods Vehicles (HGV) maintenance. The CCMTA's National Safety Code Standard 11 requires all commercial vehicles to undergo regular safety inspections, which include checking the brakes, steering, suspension, and tires, among other components [13].

The Commercial Vehicle Safety Alliance (CVSA) inspection levels are not referenced within the CCMTA's National Safety Code Standard 11 but are considered industry best practices and are typically required by provincial authorities.

Vehicle Inspection

Regular driver walk-around checks are widely considered best practice to identify any visible defects or issues with the vehicle before starting a journey. These checks include examining the condition of the vehicle's tires, lights, and mirrors and checking for any leaks or damage to the bodywork. By adhering to the guidelines of the CCMTA, HGV operators in Canada can ensure the safety and roadworthiness of their vehicles. Some key items of a vehicle maintenance plan are as follows:

Daily Inspections - A daily inspection will occur before the vehicle is driven. This includes checking the engine oil level, transmission fluid level, coolant level, brake fluid level, and windshield washer fluid level. The driver will also inspect the tires for damage or wear and check the brakes for proper operation. Any issues will be addressed immediately before the vehicle is driven.

Regular Servicing - Regular servicing is essential for ensuring the vehicle's safe operation. The vehicle should be serviced according to the manufacturer's recommendations, including regular oil changes, filter replacements, and fluid changes. The timing of these services will depend on the manufacturer's guidelines, but generally, they should be carried out every 16,000-24,000 kilometers.

Brake Inspection - Brakes are one of the most critical components of a heavy goods vehicle, and regular inspection is essential to ensure their proper operation. Brakes should be inspected every 6 months or 40,000 kilometers, whichever comes first. This inspection should include checking the brake pads, shoes, drums, rotors, and hydraulic system for proper operation. Any issues should be addressed immediately.

Suspension Inspection - The suspension system is also a critical component of a heavy goods vehicle, and regular inspection is essential to ensure its proper operation. The suspension system should be inspected periodically per the manufacturer's instructions. This inspection should include checking the shocks, springs, and bushings for proper operation. Any issues should be addressed immediately.

Electrical System Inspection - HGVs rely on complex electrical systems to operate safely and efficiently. Proper maintenance and inspections of these systems are crucial to ensure that HGVs are roadworthy and safe.

Cooling System Inspection - The cooling system is another critical component of a heavy goods vehicle, and regular inspection is essential to ensure its proper operation. The cooling system should be inspected every 6 months or 40,000 kilometers, whichever comes first. This inspection should include checking the radiator, hoses, thermostat, and water pump for proper operation. Any issues should be addressed immediately.

Truck-tractors used for nuclear material transport tend to be relatively new and are carefully inspected before each deployment during a separate process for mechanical and electrical readiness for duty.

The CVSA provides eight levels of inspections ranging from the Level I Inspection, which evaluates both the driver and vehicle, to inspection levels with a more specific area of focus, such as Level VI for radioactive materials and Level VIII for electronic inspections.

Truck tires are inspected to ensure they are new, near new, or within wear guidelines set by the CVSA. From STS' operational experience, all road shipments originating from Canadian Nuclear Laboratories (CNL) destined for the US, transported through Ontario were subject to a CVSA Level VI inspection. These inspections were performed by Ministry of Transport Ontario (MTO) personnel and derived from a contractual requirement with the carrier [14].

Securing Loads

Nuclear material is transported in specially designed and licensed packages. These packages are robust and weigh many tons. Because these packages are so specialized and heavy, they require specific cargo securement fixtures, which are part of the package license/certificate. Special cargo fixtures ensure that the packages are properly secured to the conveyance as part of compliance with national regulations.

Commercial trucks often carry heavy loads of cargo or materials. Failure to properly secure the load can cause it to fall off the truck and hit other vehicles or create a barrier if left on the road. Catastrophic injuries or fatalities can quickly happen if other vehicles encounter fallen loads or hazardous materials left behind by a truck [15].

In contrast to standard commercial truck transports, vehicles used for nuclear transport are inspected carefully before every deployment including load securing methodology. For past STS-controlled nuclear transport operations, vehicles and drivers underwent an independent rigorous pre-inspection by a qualified mechanic and a formal CVSA inspection. The "pre-inspections" were designed to find and repair any issues before the provincial inspection to ensure that no schedule delays would impact planned transports including the securing of loads.

3.5 Driver Condition

3.5.1 Potential Causes

Driver conditions (fatigue, health, impairment, and inattentive driving) are common causes of commercial trucking accidents. Potential mitigation measures are discussed below.

3.5.2 Potential Mitigation Measures

Driver Fatigue

Driver fatigue is another common cause associated with commercial truck-tractor incidents. In June 2021, amendments to the Commercial Vehicle Drivers Hours of Service Regulations [16] came into effect mandating no driver to accumulate more than 13 hours driving time in a day and electronic logging devices for federally regulated motor carriers. These updates are intended to help more accurately track drivers' work/rest hours and reduce the risk of fatigue.

Unlike truck drivers in standard commercial road transport, truck drivers engaged in nuclear material transportation are not under pressure to achieve tight profit-driven delivery schedules, deadlines, or similar constraints requiring long hours at the wheel. The contingent risks of "driver error, speeding, and cutting corners" are often mitigated by the

presence of security escorts, a higher standard of training and experience, and a tighter regulatory environment than that which generally exists for standard commercial trucking – which is unconstrained by these factors.

In comparison to commercial trucking conditions described above, best practice sees road transport of nuclear material conducted by a team of drivers for long-duration routes. The working recommendation is that two drivers – a primary driver and a co-driver – are assigned to each nuclear transport vehicle in rotating shifts so that driver fatigue is managed during the transport operation. Additionally, pre-departure inspections examine the driver's logs to ensure they have had sufficient rest to adequately meet all requirements during available duty hours.

The CNSC requires licensees to implement and maintain human performance programmes. Licensees typically perform a risk-informed analysis to identify safety-sensitive positions that will be subject to these requirements. REGDOC-2.2.4, Fitness for Duty: Managing Worker Fatigue [17] specifies requirements and gives guidance for managing worker fatigue.

Driver Health

Drivers may schedule routine physical examinations to reduce the likelihood of heart attacks, strokes, or enroute medical emergencies caused by health problems such as diabetes, kidney disease, or other long-term debilitating conditions. By reducing the chance of a driver suffering a medical condition during a transport, the likelihood of an accident occurring during a medical emergency is reduced. Notably, the release of, or requirement for, submittal of personal medical information may be unlawful in many legal jurisdictions, both in Canada and the US.

Driver Impairment

Impairment is also a major factor that can increase the risk of road accidents, as drivers under the influence of drugs or alcohol lack the coherence to suitably control a vehicle. Nuclear material transport drivers should participate in a continuous drug and alcohol screening process to maintain their government-issued security clearances. This greatly reduces the likelihood of driver impairment due to the influence of drugs or alcohol. Employers must make the decision to implement drug and alcohol testing for their employees. Within nuclear regulation, the CNSC's REGDOC-2.2.4, Fitness for Duty, Volume II: Managing Alcohol and Drug Use [18] establishes requirements and guidance for managing workers fitness for duty with respect to drug and alcohol use. The intention of the document is for high-security sites as defined within the NSR [4] with requirements and guidance being applicable to workers with "safety critical" or "safety-sensitive" positions defined within. Notably, dangerous goods drivers are not defined within this document, but a risk-based analysis of the role would suitably inform the requirement.

Human performance is a contributor to the safe and secure transport of radioactive material. Implementing a fitness for duty program could provide assurance that drivers or others in operational roles have the capacity and are free of any impairment that could hinder their ability to competently and safely perform duties so that they do not pose a safety or security risk.

Fitness for duty assessments could include, but are not limited to, medical assessments, psychological assessments, occupational fitness assessments, alcohol, and drug testing.

The NTS fitness for duty program includes drug and alcohol testing, fatigue management policy and driver terms and conditions designed to aid fitness for duty (see **Section 4.1**).

Inattentive Driving

Best practices for nuclear transportation typically see two drivers (or a driver plus security escort) being present in the cargo truck cab, to ensure attentive driving and increase the ability to respond to operational complexities. For example, ensuring both a driver and co-driver are awake and alert in the truck cab at all times facilitates communications and response protocols both under routine circumstances and under duress. Two drivers will allow most emergencies to be handled while still ensuring control of the cargo vehicle itself. Additionally, the use of escort personnel may serve a similar function in maintaining control of cargo during any emergencies while having secure communication links to the relevant response arrangements.

Operationally, routine communications such as check-calls are typically streamlined by using a single button press to transmit “all is well” messages to the TCC to minimize any distraction potential. This helps to further reduce the hazards of distracted driving. Having security escort personnel accompanying the truck also acts to forestall careless or reckless behaviour as an additional layer of assurance. While accidents caused by other drivers are a possibility, nuclear transport operational protocols are designed to reduce the probability of any nuclear material transport driver behaving inattentively at any time.

3.6 Adverse Weather Conditions Considerations

3.6.1 Potential Causes

Section 6.2.1.4 of the previous work package [1] illustrates that most collisions involving truck-tractors and heavy vehicles in different provinces occurred during “clear” weather conditions. This is expected to be due to most transports taking place during clear conditions, however the potential impacts of adverse weather must remain a pertinent planning consideration.

High winds, difficult terrain, narrow highways, icy roads, and heavy rain or snowfall all pose different risks to commercial vehicle drivers. Truck drivers can cause collisions if they lose control when driving in dangerous weather. [15]

3.6.2 Potential Mitigation Measures

Monitoring Weather Conditions

Inclement weather is always a possibility within Canada, especially during the winter months. A series of pre-shipment weather checks can mitigate this. Under unexpected dangerous weather or storms, it is considered standard protocol to notify the shipper, law enforcement authorities, and regulators so that a “go/no go” decision can be made to delay the shipment or proceed, with the possible need to shelter in a safe harbour enroute.

Based on STS experience operating within Canada, out of more than 200 nuclear material transport operations carried out over a three-year period, only one has encountered circumstances that forced a cancellation. This was because of Hurricane Dorian forcing a shipment headed to the Buffalo port of entry to turn around. The decision was made to pause further shipments for a week while bridges along the route were assessed.

3.7 Road Surface Conditions

3.7.1 Potential Causes

As identified within the previous work packages [1], adverse road surface conditions could lead to truck collisions as they relate to loose snow, slush, ice, mud, sand, gravel and/or spills.

3.7.2 Potential Mitigation Measures

As noted in previous sections, route planning and route reconnaissance (see **Section 3.3.2**) and monitoring the impacts from inclement weather (see **Section 3.6.2**) are some measures that can be implemented to mitigate impacts from adverse road conditions. Furthermore, ongoing monitoring of traffic and road conditions by the TCC with feedback to the driver, can help provide valuable information to the drivers regarding hazardous road surface conditions during transport. Ongoing assessment of the transport will provide decision makers (TCC) with the information required to take action to mitigate the risks associated with poor road surface conditions, by means such as re-routing or rescheduling transports if necessary.

4 Rail Operations

Previous work packages discussed rail collisions within Section 6.2.2.3 [1], identifying the frequency and percentage of collisions under defined derailment scenarios. Data was separated for collisions in which rail vehicle remains on track and those in which a derailment occurs, with derailment defined as any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to the track or equipment. Notably, 63% of collisions from rail source data (the Transportation Safety Board of Canada (TSB) data dictionary [19]) within the Transportation Collision Data Analysis Report [1] involved a derailment.

As described therein (in Section 6.3.2 [1]), train operators' actions and conditions were not recorded in the TSB dataset for collisions. In addition, environmental conditions, including weather, surface, and lighting conditions were only available for a small fraction of train collisions in Canada. In the absence of such detailed information, the contributing factors for train collisions could not be identified. However, over several decades, rail assets have been developed and engineered through the implementation of electrical and mechanical systems to remove factors that could lead to collision or derailment due to human error. Detailed below are several key safety systems and factors that are mandated and incorporated in NTS' rail assets and can be considered best practice for mitigations associated with causes of derailment which include: rail operator fitness for duty; driver training; train safety features, rail conveyance and equipment testing, inspection and maintenance, informed decision-making, and route planning.

Examples of NTS owned rail wagon assets are included in **Appendix A**.

4.1 Rail Operator Fitness for Duty

Driver assessment should occur on a regular basis. For example, NTS rail procedures require a full medical examination every 3 years for drivers under the age of 55 and annually once aged 55 and over. In addition, NTS operates drugs and alcohol screening supported by the organization's Drugs and Alcohol Policy.

A robust fatigue management policy is essential to ensure all drivers are driving fully alert and rested. The fatigue management policy is supported by continuous fatigue monitoring, which is a complex formula accounting for the previous and current weeks' work, while also incorporating hours worked, start and end of shift times, continuous shifts worked and degree of movement in hours between the start of shifts.

For NTS, all planned base driver rosters are checked against a fatigue index (see **Figure 6**) to ensure that acceptable parameters are not exceeded on a planned basis. If a driver triggers a certain threshold on the fatigue index due to additional or extended working, the policy will address this with several potential interventions.

Figure 6 NTS Fatigue Index Calculator example

Fatigue Index Calculator
Read the manual before using! Go to <http://www.hse.gov.uk/RESEARCH/rpd/rtd446g.pdf>

Company: _____ Location: _____ Shift ID: _____ Date: _____ Mode: ☐ Fatigue ☐ Defaults ☐ Reset Index

Assessor: _____
☐ Display schedule ☐ Display charts
© Crown Copyright 2005 Version 2.3

Comp	On Duty	Off Duty	Shift Type / Location	Proposed Time	On Duty Length	Rest Length	Average duty time (h)	On Duty/Rest ratio	On Duty/Rest ratio	Shift Type / Shifts (percentage)	Fatigue Index
1	03:00	09:00	Default	Default	6h	Fully Rested	6h	0.1	2.6	1.6	4.3
3	12:00	22:00	Default	Default	10h	2d 3h	5h 20m	1.0	0.7	1.0	2.7
4	10:00	15:15	Default	Default	5h 15m	12h	5h 19m	1.6	0.4	0.1	2.1
5	03:15	11:50	Default	Default	8h 35m	12h	5h 58m	2.3	2.5	2.4	7.0
6	13:30	21:25	Default	Default	7h 55m	1d 1h 40m	6h 18m	3.6	0.7	0.6	4.8
7	14:45	22:00	Default	Default	7h 15m	17h 20m	6h 26m	3.5	0.9	0.8	5.1
9	03:15	13:15	Default	Default	10h	1d 5h 15m	6h 7m	4.0	2.5	2.9	9.1
10	03:15	13:15	Default	Default	10h	14h	6h 30m	11.9	2.5	2.9	16.6
11	03:15	13:15	Default	Default	10h	14h	6h 49m	17.5	2.5	2.9	21.9
12	02:50	11:21	Default	Default	8h 31m	13h 35m	6h 58m	21.0	3.0	2.9	25.7
13	03:00	09:00	Default	Default	6h	15h 39m	6h 53m	23.5	2.6	1.6	26.8
14	22:50	09:50	Default	Default	11h	1d 13h 50m	6h 42m	15.0	12.7	13.5	37.2

It is important that fatigue awareness and management training is carried out for all safety-critical workers as a minimum. This includes a pre-shift self-checklist for drivers to complete to assess their fitness for duty prior to arriving at work.

Driver's terms and conditions also play a vital role in ensuring drivers' fatigue is managed correctly. These terms and conditions may address the following key areas:

1. Salaried payment with no material incentive to work above planned hours on a regular basis.
2. Minimum rest between shifts (e.g., 12 hours for NTS rail)
3. Maximum planned shift length (e.g., 12 hours, with no driving into the 11th hour for NTS rail)
4. Maximum amendments to planned start times.
5. Continuous driving time limit (e.g., 5 hours for NTS rail)
6. Authorized diagrams of routing for each shift
7. Regular breaks at authorized and equipped break facilities incorporated into each shift.

4.2 Driver Training

As with road transports, driver training for relevant traincrew is one of the most effective measures to mitigate accidents on the railway. On appointment, individual training needs analysis is undertaken to determine the specific training required before they can carry out unsupervised train driving duties. This will typically consist of the following key components and take approximately 1 year to complete based on no previous train driving experience.

Induction & Cab Experience (two weeks) – The induction and cab experience process provides an initial introduction to the company and covers all key policies, non-technical skills, and initial nuclear industry awareness training.

This is followed by a period of cab experience for new recruits who have never driven trains before, which involves them accompanying existing NTS train services. Nuclear services are not utilised for this purpose.

Rules Training (eight weeks) – New recruits are then required to study all current railway rules and sit through an examination, which they must successfully pass to continue training.

Traction Training (one week per locomotive type) – On successfully completing Rules Training, new recruits will then commence traction training on designated types of locomotives the company operates. This training will include classroom, static and practical training.

Practical Train Handling (twenty weeks) – Trainee drivers must then complete a minimum of 225 hours practical full train driving under qualified mentor supervision. At the end of this process, they will receive a full driving assessment to determine whether they are competent to drive.

Route Knowledge (three weeks per route)– Trainee drivers will then be assigned a minimum of 2 core routes to learn. Route learning is completed through a combination of classroom (route risk assessment, maps, and video) and practical experience. This element will be completed over a planned, predetermined continuous period before a route assessment takes place, which will take the form of a question paper and as required, a practical assessment. Once qualified, any further route learning required will be undertaken, assessed, and signed off following the same process.

Post Qualification (two years) – Once qualified, the driver will be assigned to a further 2-year post-qualification phase where they will receive a greater number of assessments to ensure they are working with the correct skill and knowledge.

4.3 Train Safety Features

4.3.1 Train Protection Warning System (TPWS)

The purpose of the TPWS is to automatically activate the train brakes through detection from the locomotive in the event of excessive speed being detected on the approach to signals or when a SPAD. SPAD is referred to as passing a stop signal in Canada and refers to a train passing a stop signal when not allowed to do so.

TPWS installed on locomotives need to be compatible with installed infrastructure equipment throughout the chosen rail network to operate safely and effectively.

TPWS will only trigger in the event of an incident, so it is important to test the system to ensure reliability. During the locomotives' maintenance, depots utilize handheld signal generators to emit sequences of signals to the locomotive antennas.

The simulated signals demonstrate that the locomotive brakes deploy in the event of both overspeed and SPADs. Typical locomotives used for nuclear material transport carry out an automated self-test on each startup to prove system functionality. Asset managers such as NTS are expected to conduct more in-depth depot checks on each locomotive at a minimum of every six months.

4.3.2 Automatic Warning System (AWS)

The AWS is installed to provide train drivers with an audible warning and visual reminder that they are approaching a signal at caution. Failure to acknowledge an approaching caution signal would result in automatic application of the locomotive's brakes. The AWS is connected to a visual and audible display in the drivers' cab.

If the signal being approached displays a restrictive aspect (red, yellow, or double yellow), the AWS will sound a continuous horn. The driver then has approximately 2 seconds to cancel the warning by pressing and releasing the AWS/TPWS acknowledgement button. On cancelling the warning, the horn then stops, and the visual indicator changes to a pattern of black and yellow spokes, which persists until the next AWS magnet and reminds the driver of the restrictive aspect.

As a fail-safe mechanism, the AWS will not be cancelled if the driver fails to cancel the warning in time or if the driver collapses onto the button or keeps it held down. The emergency brake will apply and bring the train to a stand.

To ensure function of the AWS, maintenance depots periodically simulate the magnetic fields of the infrastructure to conduct testing and maintenance. These sequences then prove that systems on the locomotives are operating correctly.

4.3.3 On Train Data Recorder / Event Recorder (OTDR)

An OTDR, also known as an event recorder or black box, is an important safety feature on locomotives as it records a variety of data related to the train's operation. This data can be used to investigate accidents and near-misses, among other incident types, to determine their cause and prevent them from happening in the future.

The OTDR records information such as train speed, brake status, throttle position, horn and bell usage, and other important parameters. This data can be used to reconstruct the sequence of events leading up to an incident and determine the cause. Safety experts can identify trends and patterns indicating potential safety issues by analysing this data.

In addition, the data recorder can be used to monitor the performance of the train and its crew. For example, if the data recorder shows that a train has been consistently exceeding speed limits, steps can be taken to address the issue and prevent accidents from occurring.

Overall, an on-train data recorder is an important preventative safety tool that can be used to ensure the continued safe operation of the train. By providing valuable data that can be used to improve safety practices, the data recorder helps to protect assets and traincrew.

Data recorders at NTS have a functional check every three months to ensure they operate correctly.

4.3.4 Deadman's Switch Device (DSD) Vigilance System

DSD vigilance is a critical safety feature on locomotives that ensures the driver is alert and responsive while operating the train. In simple terms, the DSD system requires drivers to acknowledge their presence and attentiveness by pressing a button or pedal at regular intervals. If the driver fails to respond to the audible warning, the system will automatically apply the emergency brakes, stopping the train.

Testing the DSD vigilance system is essential to ensure the system is in good working order and can maintain the safety of train operations. Regular testing and maintenance of the DSD system can help prevent accidents, injuries, and fatalities. NTS tests the DSD & Vigilance operation on every locomotive every three months.

4.4 Rail Conveyance and Equipment Testing, Inspection and Maintenance

4.4.1 Rail Assets

To ensure the safety of rail assets and reduce the likelihood of derailment, the rail conveyance and equipment must be tested, inspected, maintained, and managed effectively.

- Each asset needs to be maintained in accordance with an approved maintenance plan.
- Each maintenance plan needs to be updated in the event of changes to an asset.
- Internal and external assurance of maintenance carried out on the vehicles needs to be conducted.
- Safety critical components must be identified, procured, and tracked in line with approved robust processes.
- The safety systems on an asset must be in place, in good working order and tested regularly.
- Maintenance staff working on rail vehicles should be assessed as competent.

4.4.2 Rail Conveyance and Equipment Testing, Inspection and Maintenance Frequencies

The maintenance of a rail asset is derived by adopting a combination of both best practices and component manufacturer recommendations. Testing, inspection, and maintenance intervals are defined by either elapsed time or on a usage basis measured in track kilometers. An evaluation of the predicted annual mileage is made, and then an alignment is done between the 2 variables where possible. These recommendations are reviewed and are grouped to form exams with tasks to adopt these into a Vehicle Maintenance Instruction (VMI). **Appendix B** details a list of job codes within the VMI, these codes are linked to the relevant test procedures for each assets specific testing, maintenance, and inspection requirements. VMIs are established and utilised to define and undertake maintenance for each rail vehicle type (locomotives and rail wagons), wider maintenance requirements for transport packages are the responsibility of the owner and do not sit within the remit of the NTS VMI for rail operations.

4.4.3 Refinement of a Rail Maintenance Plan

Based on NTS' experience, the following factors outlined below are considered those that would lead to a vehicle maintenance instruction (VMI) being refined.

Routine Review - On a 12-month basis, a review will incorporate any minor corrections noted on the VMI at that time. This review will also incorporate any relevant information that may have come from specialized maintenance bulletins produced within those 12 months.

Safety Performance Monitoring Reporting (SPM) - SPM is captured monthly for each asset type. The report investigates trends in defects of safety-related components and mileage of vehicles and captures key information concerning critically defined maintenance periodicities. The SPM report would also incorporate national-level reports of defective components that are picked up externally.

Modifications to Vehicle Structure or Components - Any modifications that have been carried out to the vehicle need to go through a formal engineering change process. The engineering change process is used to validate that the changes made do not add any additional risk to the operation of the vehicle on the rail network and that the modification complies with all applicable standards.

Changes of Equipment from that Captured within the Original VMI - If a component is replaced for a similar component with the same functionality from a different supplier, this needs to be assessed formally through the engineering change process.

Change in Vehicle Duty Cycle or Environment - As noted above, the vehicle duty cycle plays an important part in the maintenance regimen for a rail asset. In some cases, infrequent use can be as damaging to a vehicle as frequent use. Competent engineers need to assess a change in predicted use, with the effect on the maintenance cycle assessed and adjusted accordingly. Consideration should also be given to any potential change in operating environment for the vehicle.

4.5 Informed Decision-Making

There may be situations which require a decision to be made before a shipment. This may be a security alert at the departing location and/or receipting location or sudden unavailability of the infrastructure (e.g., tracks or cranes). A risk-based approach should be followed, with the health and safety of all personnel involved taking priority in decision-making.

The risk appetite of the operations should be well understood by the operational leads of the business. Should some form of concern be raised prior to transport, the operational support team should convene to agree on whether or not to go ahead with the shipment based upon pre-determined criteria for the decision making, set by the carriers and communicated to the transport teams.

4.5.1 The Impact of Weather

As with road operations, weather forms an element of planning for rail operations. Weather conditions can impact transport operations: prior to the transport taking place; during the transport; and sometimes after the transport has concluded. At all times, the health, well-being, and overall safety of personnel involved is a primary consideration, and if at any point a transport operation needs to be paused due to adverse weather conditions, then a decision must be made to do so.

For example, NTS utilizes UK Met Office weather forecasts, and the dedicated NTS 24/7 control room is responsible for monitoring warnings and reacting to applicable inclement weather warnings. The control room team is signed up to receive automated messages of all-weather warnings. In Canada, agencies such as Environment Canada provide periodic weather data that can be used to support operational preparations.

Within the weather escalation process, the following risk factors need to be considered:

- Location – where is the weather warning situated?
- Direction of travel – is the weather front moving? Which direction and where will it end up?
- Timings – how long is the warning in place? When will the weather front hit that area?
- Staff – Are staff currently in that location? Are staff currently travelling to and from that location? Are staff planned to be in that location during the weather warning?
- Transport operations – are any transport operations taking place in that location? Are there any transport operations being affected already? Are there any transport operations which will be affected imminently? Are there any transport operations likely to be impacted upon in the future?
- Equipment/assets – are there any other pieces of equipment/assets that could be impacted?

4.6 Rail Route Planning

Route planning for rail operations is typically more constrained than that of planning for road due to the limited path (track) options. However, route planning is still a key part of planning for nuclear transport operations by rail. Some key considerations are as follows:

Train Weight, Length and Gauging Characteristics - In selecting the safest and most practicable rail route, the locomotive and wagon's specific design characteristics and the railway infrastructure's specific constraints need to be reviewed. This review ensures at the outset that the route has the capability to accommodate the weight, length and gauging of the nuclear rail movement.

Track/lineside Condition and Signalling Arrangements - Where possible, the route should contain the most up-to-date track and signalling arrangements, which can be checked with the infrastructure provider. Defect and repair records are available from the provider, together with any relevant upgrade work. Further consideration should be given to significant infrastructure items such as level crossings and stations, where there is an increased risk of public interface.

Route Resilience & Performance and Incident History - A resilience assessment can be carried out on the route to highlight potential areas of weakness or higher risk. For example, a route very close to the coast could be prone to flooding or landslides. Performance information is also typically available to aid in determining the reliability of a route and enable an evaluation of the likelihood of disruption to rail movements on that route. Alternative diversionary options should also be assessed to enable alternative routes to be utilized where possible if the original route is unavailable.

A review of incident history can also be undertaken to identify safety performance on the route and key trends in safety risks. This may serve to identify if a particular route has a significantly better safety record than another and influence route decisions.

Route Access - Another factor that should be considered is the train movements' ability to gain access to the route on a planned basis. Assessment of the time effectiveness of a route can ensure that train services are on a public network for a minimal amount of time. The route should enable the train to operate without stopping, to accommodate other traffic, and to minimize the potential for tampering while standing out on the network.

Effective route planning is achieved through balance of identified risks and understanding the various decision-making influences on the transport. Best practice sees safety, security and operational logistics working together to undertake an appropriate route selection process. A route risk assessment should be completed when undertaking the route evaluation and selection process. This will provide a comprehensive document detailing the identified risks. This will enable specific mitigations to be identified, actioned, and recorded (e.g., a speed restriction due to a poorly sighted signal). Further, the document forms a key part of traincrew route learning, where it will inform those learning or refreshing the route with key information that they must learn and understand. The risk assessment document can ultimately form part of the route learning evaluation process before a train crew member is officially signed off as competent to drive that route.

Any updates to the route that create new key information or key risks must be captured in a formal review process. A review process can be instigated by notified changes to the infrastructure, observations, or hazard reports the traincrew generates as they operate the route.

An example of a current route risk assessment is included in **Appendix C – Route Risk Assessment Sellafield to Carlisle**, which details the UK line that carries a significant level of nuclear rail traffic.

5 Emergency Response and Transport Security Considerations

5.1 Emergency Response

5.1.1 Overview

Radioactive materials present a range of potential hazards during transport, and the purpose of regulation and effective emergency response arrangements is to protect persons, property and the environment from hazards posed by radioactive material during transport. In the event of a transport emergency involving radioactive material in Canada, the consignor and carrier must have measures in place to respond to an emergency involving the transport of the material.

NWMO will provide an emergency response plan to Canadian regulatory agencies to demonstrate that appropriate emergency measures are in place and that information is available to public response agencies. The purpose of the emergency response plan is to ensure coordination among NWMO, provincial and local first responders as well as federal agencies.

Additionally, for Category II security nuclear transports, a suitable contingency plan in the event of a security incident included within the TSP will also be expected to meet the requirements of the NSR as part of the licence requirements to transport nuclear materials [4].

These plans provide information to ensure coordination among federal, provincial, and local first responders, should an incident take place. Emergency Management Plans contain contingency plans for various off-normal situations and include step-by-step procedures that tell drivers exactly what to do in the event of incidents.

Appendix D provides typical key roles and responsibilities associated with incident response.

5.1.2 Drills and Exercises

Exercises generally have three main purposes which are to validate plans, develop staff competencies/practice roles, and to test well established procedures. Exercising all emergency response arrangements is essential to identify learning opportunities which can improve processes and prevent repeat issues from occurring.

Exercises can take various forms, including live exercises or table-top exercises, and can include a single organisation or involve multiple agencies.

All emergency exercises are scenarios based around a plausible incident; examples of scenarios could include the following:

- Protester activity
- Derailment of nuclear services involving emergency services
- Crane failure during lifting operations

- Security incident on a rail service or road shipments
- Road traffic collision on a highway/freeway/road

Emergency plans are exercised through simulated situations. These situations are designed to evaluate the effectiveness of the response organization's emergency plans, procedures, and capabilities by identifying problems or gaps that can be resolved prior to a real emergency. They also identify good practices to be reinforced and provide opportunities for organizations and personnel to test their capabilities to respond to a particular component of a plan.

5.1.3 Incident Reporting

Robust communications capability between all involved parties connected through the TCC enables timely incident response and reporting. Communications should be routinely tested, with suitable redundancies and contingencies in place ahead of operations taking place.

For transport operations within Canada, the CNSC have a 24/7 duty officer telephone line for reporting in the event of an emergency involving a nuclear facility or radioactive materials. The CNSC's role in an emergency is to monitor and evaluate the actions while providing technical advice to federal and provincial response authorities. The CNSC will also inform government and the public regarding its assessment of the situation. Any event involving the loss or damage of nuclear material or the threat of theft, smuggling, vandalism, or terrorist activity involving nuclear material, is reportable to the CNSC.

5.1.4 Incident Support

In addition to the CNSC, Transport Canada operates the Canadian Transport Emergency Centre (CANUTEC) [20] is a national advisory service that helps emergency responders handle dangerous goods emergencies on a 24/7 basis. Staff include bilingual scientists in chemistry or related fields and are trained emergency response. CANUTEC's emergency response advisors provide immediate advice on actions to take and to avoid during a dangerous goods emergency.

5.2 Transportation Command Centre (TCC)

The purpose of the Transportation Command Centre (TCC) is to act as a centralised point of contact for the carrier to coordinate normal transport conditions, as well as accident or incident conditions during a transport. The role of the TCC is to stand up and coordinate response at a tactical level, liaising with all relevant response organizations. The TCC should have attendance from, or communications links to, involved multi-agencies (e.g., carrier, response force, emergency services, consignor, consignee etc.).

5.3 Transport Security

Transport security requires a bespoke approach to that of a licensed nuclear facility. Section 5 of the NSR [4] sets the requirements to obtain a license to transport Category I, II or III nuclear material within Canada and is aligned to international security recommendations and conventions communicated by the IAEA. Part B of REGDOC-2.12.3: Security of Nuclear Substances: Sealed Sources and Category I, II and III Nuclear Material [21] provides information and guidance on how to comply with the security measures for transport of nuclear material, as set out within the NSR.

5.3.1 Escorts

For security escort arrangements, REGDOC-2.12.3 [21] states that any transport of Category II material “should be accompanied by one or more escorts”. Security escorts are required to maintain constant surveillance of the cargo by travelling in either an accompanying vehicle or in the cargo carrying vehicle. Security escorts will also typically hold secure communications links to the relevant response forces along the planned route and the TCC.

5.3.2 Transportation Security Plans

The NSR details that any application for a license to transport Category I, II or III nuclear material in Canada shall contain (in addition to the requirements set out within the PTNSR), a written Transportation Security Plan (TSP) including:

- Name, quantity, radiation levels and physical and chemical characteristics of the material in transport
- Communications arrangements for the transport
- Suitable threat assessment
- Response force arrangements
- Conveyance description
- The planned route
- Proposed security arrangements for the transport
- Any alternate / contingency routing arrangements

The TSP is a key operational document that is securely passed to the necessary parties prior to any transport operation taking place. Periodic exercising of arrangements established within transportation security plans is also a common requirement for carriers of nuclear material.

6 Human Performance Approach – NTS Rail

The following section outlines NTS' approach to human performance for rail operations. Some elements of human performance are cross cutting and practices identified herein (competency management and recruitment) can be applied to wider nuclear transport operations (i.e., different modes of transport or various radioactive material transport programs); however, all details are derived from the operational activity of Direct Rail Services (DRS), the rail organization operated by NTS.

6.1 Human Performance Program

6.1.1 Competency Management

Traincrew

A qualified train driver will undergo a planned competency assessment cycle that details at least two practical (or locomotive) download assessments for each specific competency within a 2-year cycle, as discussed within **Section 4.2**. At the end of each 2-year cycle, the driver will re-sit their railway rules exam and must pass this exam and all assessments to maintain their driving competency. This process is formally documented and recorded in a Competency Management System (CMS), which is subject to annual internal and external assurance audits. The CMS system also maintains accurate train driver route and traction competency records.

If a driver is involved in an incident and is deemed to have development requirements following the incident investigation, they may be placed on a formal Competency Development Plan (CDP). The CDP will detail several additional measures to support the required development, such as an increased number of assessments in the 2-year period, a particular focus on non-technical skills or refreshing a route. These plans are formally documented, reviewed, and signed off as complete when the driver successfully completes them.

Engineering Staff

NTS has an internal engineering training manager who delivers training using a network of approved suppliers to train engineers on various aspects of rail vehicle asset maintenance. It is a minimum requirement that any full-time engineer has a certified, recognized qualification in a mechanical or electrical engineering discipline and has gained experience using these skills in a real-world environment before being assessed as competent on DRS rail vehicles. Initial assessments are carried out using a mix of on-the-job show-and-tell evidence and classroom-based examinations.

NTS engineering teams have certified assessors who maintain a continual check on continued competencies. Competencies are assessed based on a schedule or where there is a reason to call into doubt an engineer's competence through an observed error. At the point of re-assessment, the engineer must be able to demonstrate continued competence to an approved assessor, where they must provide evidence of work carried out over the previous 24 months and by way of a further practical assessment if deemed necessary.

Anyone failing to meet the competency requirements will no longer be able to carry out duties on the asset in question.

6.1.2 Traincrew Recruitment

Traincrew recruitment is considered a multi-level process. Typically, Traincrew can be recruited through the following mechanisms:

- 1) New entrants to the industry
- 2) Qualified drivers from another train operating company
- 3) Existing employees progressing from non-driving positions.

To be considered for a driving position, an individual must successfully pass several industry-standard psychometric tests, attend a panel interview, pass an industry-standard medical examination, and obtain the necessary level of security clearance.

7 Key Management Aspects – NTS Rail

The following section outlines NTS's management approach for rail operations. Some of the management methods are cross cutting and practices identified herein can be applied to wider nuclear transport operations (i.e., different modes of transport or various radioactive material transport programs); however, all details are derived from the operational activity of Direct Rail Services (DRS), the rail organization operated by NTS.

7.1 Organization

While legal responsibilities are assigned to roles within the organization, NTS's experience is that the most effective way to manage safety is to enable the transport operations and engineering teams to take ownership and accountability for transportation safety. It is important to recognize this accountability in organizational design to ensure there is a sufficiently skilled and trained resource to effectively carry out all the work associated with the safety of rail transport operations.

Notably, the most effective approach to safety management (across all levels of the business) is delivered when the operational division that is assigned ownership and responsibility has the tools, capability and resources required to execute their work. For large and complex organizations, a Responsible, Accountable, Consulted, Informed (RACI) matrix for key tasks can be implemented. Ensuring these elements are clearly defined, and the necessary training, equipment, and resources are in place to support those identified as responsible and accountable will enhance the safety capability of the organization.

Delivering training and safety engagement takes considerable time and resources, both in terms of those delivering and those being trained. Therefore, the organization must recognize the time required and plan its resource levels and rosters accordingly, so these key activities can occur with regularity and timeliness.

7.2 Risk Management

A robust risk management plan underpins the approach to safely transporting nuclear material. The purpose of such a system ensures continued safe operations, while maintaining public confidence in the ability to conduct such transports.

At NTS, internal monitoring is conducted against three key areas:

1. Proactive inspections
2. Internal audit and assurance plan
3. Incident investigation data

Each element of findings, whether positive, minor, or major non-conformances, are assigned an immediate and root cause criterion. The latest information is then transposed into the risk bowtie to support the status of controls and actions as a red, amber, or green format representing the status of the actions (red: incomplete, amber: ongoing and green: complete).

In managing strategic transport risk, NTS utilizes a risk "bowtie" methodology. The risk bowtie method is a visual representation of the impacts of a hazard, the risk it represents, the associated conceivable consequences and the controls that should be put in place.

This process must be closely aligned with the overall business risk appetite while drawing upon all influencing areas across the organization to populate the template and develop a suitable risk profile properly. A template of the NTS Strategic Risk for derailment can be found in **Appendix E**. Risk bowties are periodically visited and revised to ensure that actions and controls are being captured and risks appropriately managed. This is overseen by the risk owners and fed into the relevant governance levels throughout the business.

7.3 Performance Management in Engineering Maintenance

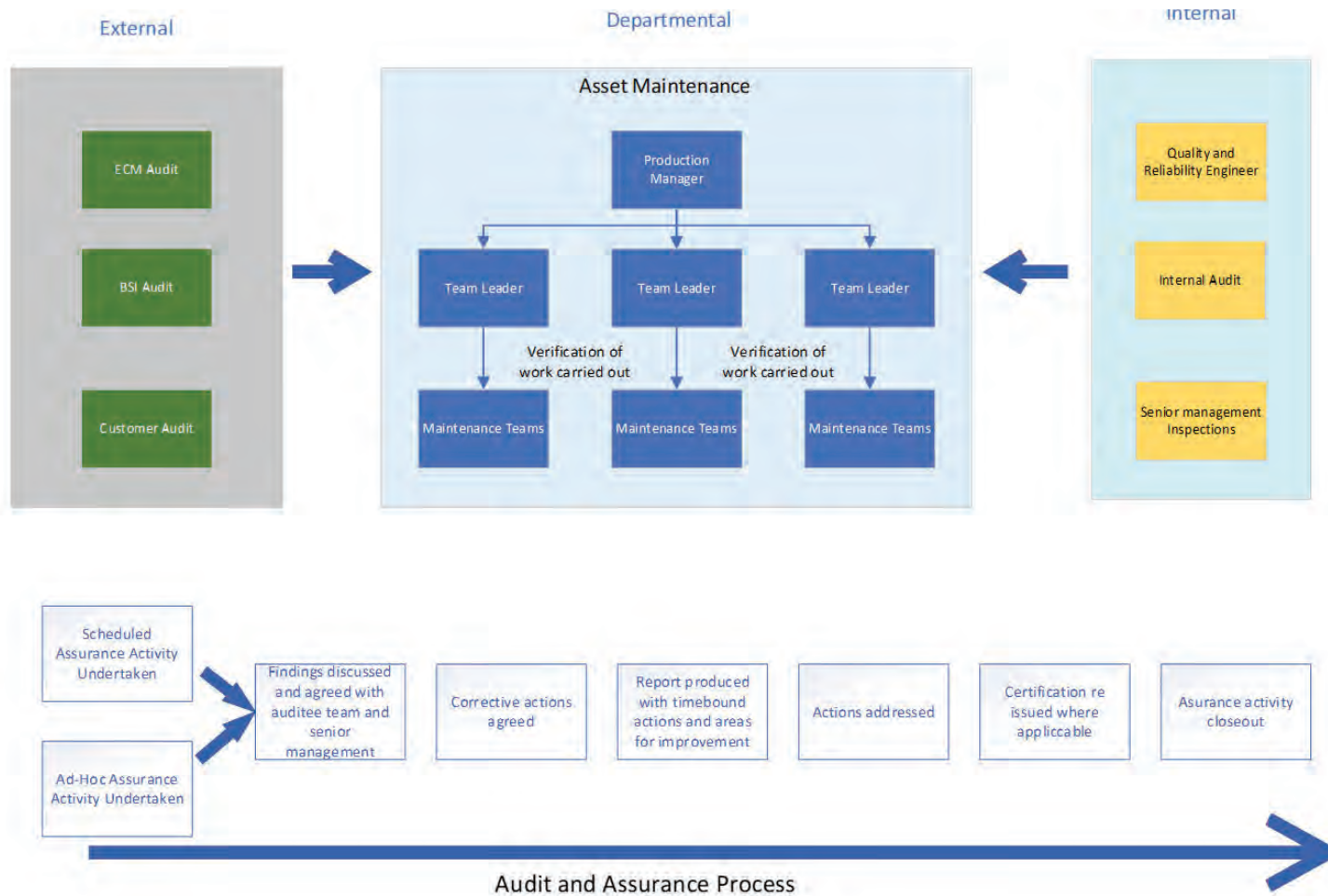
The purpose of assurance in engineering maintenance is to ensure that maintenance activities are performed consistently and that the equipment or systems being maintained remain safe, reliable, and available. Assurance is an essential part of maintenance management, as it provides a systematic and proactive approach to identifying potential issues and risks and ensures that appropriate measures are taken to mitigate them.

Assurance in engineering maintenance involves a range of activities, including:

- Compliance with regulatory requirements and industry standards.
- Implementation of best practices and procedures for maintenance activities.
- Use of appropriate tools and technologies to support maintenance activities.
- Training and development of maintenance personnel.
- Monitoring and measurement of maintenance performance.
- Continuous improvement of maintenance processes and systems.

Figure 7, provides a visual overview of these activities conducted within NTS.

Figure 7 Audit and assurance process



Assurance activities can be categorized under three levels; External, Internal and Departmental, all of which can be both planned and ad hoc. Planned audits are scheduled on a recurring basis. Typically, these are annually for Internal and External and daily for departmental-level checks and verifications. Ad hoc audits usually arise from a concern raised, and this may be an incorrect procedure being followed, a concerning trend or a result of another investigation (failure of asset, accident/incident).

7.3.1 External Audits

External assurance activities are carried out by organizations with no direct link to the delivery of maintenance, providing an independent review of activities undertaken by the maintenance teams.

Entities in Charge of Maintenance (ECM) Audit - Annual audits by an approved ECM certification body to ensure that NTS is meeting their requirements under the ECM regulations in the delivery of maintenance of assets. This audit looks at all aspects of engineering and, with regards to maintenance, will focus on key areas such as competence management, management of calibrated tooling, use of the asset management system and critical component tracking.

The British Standards Institution (BSI) Audit – NTS holds certification against various International Organization for Standardization (ISO) to which the BSI conduct periodic audits against to verify alignment or certification and provide confidence to our stakeholders and customers. These ISO standards include elements such as business continuity, health and safety and management systems.

Customer Audit - NTS maintains leased assets and assets operated by other rail operators. Leasing companies and customers conduct annual audits on NTS and their maintenance practices, including competence, Measurement and Test Equipment (M&TE) to ensure that NTS maintain the defined standards.

7.3.2 Internal Audits

Internal assurance is defined as assurance activities carried out by anyone within the organization or parent organization but not within the department or function carrying out the maintenance work.

Quality and Reliability Engineer - The engineer audits the work carried out by the maintenance team, with a focus on fleet reliability. This work can lead to discussions about the competence of engineers, trends in faults or component failures, proposals for improvement in working practices, proposals for modifications to the fleet and suggested training requirements for anyone involved in asset reliability or safety.

Internal Audit - Internal audit teams are independent of the maintenance department. The teams provide an independent review and assess a wide range of maintenance-related activities from procurement and storage of components and materials, inspections of lifting equipment, the validity of risk and Controlled Substances Hazardous to Health (COSHH) assessments and to ensure proper procedures are followed. Any findings from these audits are escalated to senior management, and remedies are implemented as appropriate.

Senior Management Inspections - Regular senior management inspections are carried out throughout the year. On average these will occur monthly at each maintenance location. The senior management visits focus on traditional health and safety issues, such as housekeeping, working at heights, use of Personal Protective Equipment (PPE), first aid & fire arrangements, provision of spill kits and management of COSHH substances.

7.3.3 Departmental Assurance

Within each maintenance location, there is a hierarchy of engineers, team leaders and production managers. When engineers carry out work, this is captured and signed off within an asset management system.

The work is then peer-reviewed by a team leader or production manager before release.

On occasion, a team leader or production manager will carry out physical checks of the work performed to ensure it meets an acceptable standard and to ensure that the individual has complied with the instructions given when carrying out the work. Any issues noted at any point throughout the process will lead to additional vehicle checks being made and performance discussions being held with individuals.

7.4 Personnel and Operational Safety Interface

7.4.1 Hazard Reporting

The drive to the most positive, consistent safety culture is underpinned by the highest levels of hazard reporting, in which potential incidents or actual hazards are being identified, reported, and actioned by colleagues throughout the business.

The ability to identify at-risk behaviours and near misses through a hazard reporting system enables the business to understand, in greater detail and at a greater pace, key trends and issues that can be addressed before they become incidents of increasing severity.

The feedback and action tracking associated with a successful system is key to ensuring timely, informed decisions, with actions being implemented to eliminate the risk. In addition, positive feedback loops are essential in encouraging greater reporting so that colleagues are fully aware that their reports add value to the safety of the business.

7.4.2 Safety Observations

Using unannounced safety observations can provide vital information about the levels of safety performance and culture in the business. Setting the management team with clear targets to perform such observations with defined tasks and locations to observe gathers a unique level of data on the reality of the safety performance within the business. Announced observations are also a useful tool to ensure consistent safety performance while not increasing the stress on staff that may be associated with unannounced observations.

7.4.3 Safety Engagement

Safety Leadership Tours

Conducting a programme of safety leadership tours from the Executive team and wider teams throughout the organization helps to drive a positive safety culture throughout the organization.

Tours should be documented, with any observations being built into the established hazard reporting system to ensure one central location for all safety improvement opportunities. These tours take place across various locations with the focus being to demonstrate the levels of safety in place at each respective site, ensuring that the importance of safety is fully embedded throughout all levels of the organization. Tours are typically hosted by local site staff and include representatives from leadership across the organization.

Learning Briefs

Incident learning briefs are also an effective tool for safety-focused engagement. The purpose of this briefing format is to capture the pertinent learning from any safety event or incident, to raise the level of safety awareness to the relevant teams. These briefs should be developed and issued after every safety event or incident to ensure that awareness, lessons learned, and actions are clearly communicated to all relevant teams.

Safety Briefs

Driver safety briefs held on a quarterly basis are also an excellent vehicle for safety engagement, where group discussion and ideas sharing are proven to enhance the overall approach to safety and safety performance. Safety briefs will typically last for several hours, and drivers will not be rostered to other work on the day. A regular format would include:

- Safety performance update
- Incident review – key learnings
- Rule book and standards updates
- Seasonal safety theme
- Safety hot focus topic
- Desktop/practical exercise
- Open discussion

As an example, NTS delivers over 700 safety briefs annually to ensure each driver receives 4 briefings per year. While this is a time-intensive task, these are very positively received, and when a workforce is often relatively solitary with drivers starting at a variety of times, the ability to bring a number together for collective learning and discussion is effective. Increasing additional safety briefs per annum in 2022-23 has contributed to the reduction in operational safety incidents year on year from 32 in 2021-22 to 11 incidents in 2022-23 at NTS.

7.5 Supplier and Contract Management

7.5.1 Procurement of Safety Critical Components

NTS categorizes all suppliers to afford the appropriate selection and assurance practices. The 5 supplier categories used by NTS are:

- Safety Critical Service
- Safety Critical Product
- Business Essential
- Construction and Maintenance Services
- General

Safety Critical Service - A service which can import risk on the UK mainline railway. Examples could include the procurement of track, structures, rail vehicles, component, systems, telecommunications, signalling equipment, modifications, maintenance services, other engineering activities, hire of labour, consultancy, and technical advice.

Some illustrative examples of key activities NTS classifies as 'Safety Critical Services' are as follows (note: this list is not exhaustive):

- Vehicle Overhauls
- Vehicle Exams
- Technical Consultancy
- Wheelset Overhauls
- Vehicle Lease
- Vehicle Procurement
- Bearing Overhauls
- Brake Equipment Overhauls
- Labourers
- Vehicle Modifications
- Vehicle Repairs

Safety Critical Product - Safety-critical products are defined as any product capable of importing risk to controlled rail infrastructure (such as procurement of track, rail vehicles, locomotive and wagon components, e.g., brake equipment, window wiper systems, wheelsets, TPWS equipment, brake blocks, lighting etc.). Examples of products NTS defines as safety critical are as follows (note: this list is not exhaustive):

- Brake Components
- Brake Equipment (distributor, valves etc.)
- Brake Blocks
- Vehicle Windows
- Vehicle Window Wipers
- Wheelsets (all components – pans, tyres, centres, axle, axle boxes, suspension tubes)
- Bearings (axle box, suspension tube)
- Hoses (flexible)
- Vehicle Safety Systems e.g., TPWS, AWS, Global System for Mobile Communications – Railway (GSM-R), European Train Control System (ECTS)

Business Essential - Business essential products are defined by NTS as any product or service where there are limited technical alternatives available or for which very few commercially attractive alternative suppliers are known and whose products/services are essential for business continuity. Business essential examples are as follows (note: this list is not exhaustive):

- Occupational Health Services
- Plant Hire
- Fuel Suppliers
- Cleaning Services
- Security Services
- Consultancy/Training Services

Construction and Maintenance Services - Any product or service which is procured to support general maintenance and development of NTS building infrastructure (including Construction Design and Management (CDM) duty holders) is considered as construction and maintenance services. Examples are as follows (note: this list is not exhaustive):

- Principal Contractor	- General builders work	- Gas
- Plumbing	- Civil Engineering Works	- Electrical
- Air conditioning	- Joinery Works	- Window Cleaning

General - Any product or service which is procured to support general business activity and is considered of low risk to business practices ongoing. NTS examples are as follows (note: this list is not exhaustive):

- PPE	- Lease vehicle providers	- Laundry Services
- Consumables (fasteners and fixings)	- Stationary	- Water bottle suppliers

7.5.2 Tracking of Safety Critical Components

Tracking of safety-critical components is done by serial number, using dedicated asset management software. Each component is registered against an asset when fitted and then tracked on the asset until removed through fault, recall or scheduled expiry date.

Key safety critical components to be tracked include:

- Axles (serial number, date of manufacture and last non-destructive ultrasonic test date)
- Axle Bearings (serial number, date of manufacture, date fitted to axles, date of last overhaul)
- Air Brake Distributors (serial number, date of manufacture or fitment and expiry date)
- Air Brake Hoses (serial number and expiry date tracked)
- AWS & TPWS Components (serial number and expiry date)

The purpose of tracking these components is to ensure no asset is in service with components operating outside their safe designed parameters.

8 Conclusion

This report identifies potential mitigating measures that can be implemented in the NWMO used fuel transportation program to reduce the likelihood of transportation accidents, with consideration to the types of modes and conveyances being considered by NWMO.

This report drew upon the conclusions found within NWMO Transportation Collision Data Analysis Report [1] to identify potential mitigation measures associated with a collision with a fixed or non-fixed object for road operations, and derailment for rail operations.

Transport operations in conventional commercial trucking in Canada are not subject to the additional stringent requirements in place for nuclear transport operations. As such, the experience of NTS and STS has been leveraged to provide insight into mitigating functions of an operational nuclear transport organization.

- **Section 3** provides insight into road-specific operational practices that should be considered to reduce the likelihood of transportation collisions with fixed or non-fixed objects.
- **Section 4** has highlighted the rail-specific operational mitigations that can be associated with a collision leading to derailment. While some inclusions are cross-cutting (i.e., applicable to both road and rail), the different challenges associated with each mode of transport should be noted, as this influences the differing approaches from the carrier organization.

Driver training and competency are highlighted across both road and rail operations as a fundamental element of collision mitigation, and this is true for transport risks beyond those identified within the initial work packages. Significant time and cost should be afforded to properly develop drivers to be suitably qualified for nuclear transport operations.

Vehicle maintenance and inspection for both road and rail vehicles is also a crucial element, with the different approaches for each mode detailed within this report. Establishing engineering and operational functions that can suitably carry out these crucial activities is also fundamental to mitigating transport collisions.

Similarly, route planning is an important element of the planning phase of any nuclear transport operation. The factors associated with road transport are not completely aligned with those in rail transport. However, the broad approach is similar in nature.

Organizational measures that underpin the operational undertaking of the company have also been discussed. The risk appetite of the organization should be communicated through thorough risk management processes and ultimately influence how transport operations are conducted.

Monitoring performance and auditing at multiple levels ensure that the organization's safety remains to a high standard and follows established best practices. One such measure is an incident response capability for either safety or security response arrangements. Although discussed at a high level, it is important to note that wider arrangements and considerations exist in this area to conduct transport operations safely and securely.

The submission of this report is intended to provide insight into important elements associated with transportation collision mitigation for a nuclear transport programme, drawing upon decades of operational experience to do so. These mitigation measures ensure continued safe operations vital to the nuclear fuel cycle, and this report intends to provide information to support those operations.

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Appendix A – NTS Rail Vehicles and Capabilities

NTS operates several bespoke nuclear rail assets. Each asset is designed for a specific purpose; to abide by all rail standards and meet any necessary nuclear package transport approvals. The following information outlines the three key nuclear rail assets operated and maintained by NTS.

FNA-D

The FNA-D was designed and built in 2014 as a replacement for the former (now expired) FNA wagon. It is restricted in use and is certified to convey used nuclear fuel in flasks on the UK rail network. It is also restricted to travel at a maximum speed of 95 km/h in empty and laden conditions. NTS operates and maintains a fleet of forty (40) FNA-D wagons on the UK rail infrastructure.



KUA

The KUA is designed to carry nuclear fuel for the UK Ministry of Defence (MOD). The wagon operates at a maximum of 95 km/h and has a double bogie design at each end of the vehicle to enable the gross laden weight of 149 T (tonnes) to be shared across 8 axles. NTS operates and maintains two (2) of these vehicles.



KXA-C

The KXA-C is designed to carry nuclear fuel in various specified flasks for onward international shipment by vessel. The wagon operates at a maximum of 95 km/h and has a double bogie design at each end of the vehicle to enable the maximum gross laden weight of 180 T load to be shared across 8 axles. NTS operates and maintains six (6) of these vehicles.



Appendix B – NTS Rail Maintenance Task and Periodicity

Event	Periodicity
Planned Preventative Maintenance (PPM)	6 monthly
Vehicle Inspection and Brake Test (VIBT)	12 monthly
OVERHAUL A	8 Yearly
OVERHAUL B	16 Yearly

Job No	Task	PPM	VIBT	Overhaul A	Overhaul B
B*01	Air Brake Equipment Inspect	X	X	X	X
BB01	Examine Brake Blocks	X	X	X	X
BH01	Bogie Mounted Handbrake Inspect	X	X	X	X
BM01	Bogie Brake Rigging Inspect	X	X		
BM02	Bogie Brake Rigging Gauge			X	X
BZ01	PPM Air Brake Test	X			
BZ02	VIBT Air Brake Test		X	X	X
BX01	Brake Equipment Overhaul A			X	
BX02	Brake Equipment Overhaul B				X
C*01	Bodywork & Canopy Examine	X	X	X	X
CN01	Signs & Markings	X	X	X	X
U*01	Underframe Inspect	X	X	X	X
UA01	Axleboxes / Cartridge Bearings Inspect	X	X	X	X
UB01	Buffers Inspect	X	X	X	X
UC01	Drawbar / Drawgear Inspect	X	X		
UC02	Drawbar / Drawgear Gauge			X	X
UC03	Coupling Inspect	X			
UC04	Coupling Gauge		X	X	X
UF01	Bogies Inspect	X	X		
UF02	Bogies Dismantle & Inspect			X	X
UN01	Wheelset Ultrasonic Axle Test		X	X	X
UW01	Wheels & Axles Inspect	X	X	X	X

Appendix C – Route Risk Assessment Sellafield to Carlisle

From:		Route Reference	Route Assessment Date
To:			
Assessed by		Issue Number:	
Hazard/Risk		Location & Detail	
A	Signals which have been the subject of multiple Signal Passed at Danger (SPAD) incidents, particularly where the potential consequences of a SPAD are severe, including the reasons why the signals have been passed at danger.		
B	Signal gantries with a history of SPADs or there is potential to misread signals intended for adjacent lines (reading across).		
C	Signals beyond the signal immediately applicable to the movement which become visible to drivers before, or with similar intensity to, the applicable signal (reading).		
D	Signals that are known to be affected by bright sunlight at times of the day or year (both main and shunting signals).		
E	Signals which are positioned on the right-hand side of the running line in the direction of travel and considered a risk (both main and shunting signals).		
F	Locations where braking distances between signals are inconsistent.		
G	Locations where the signal aspect sequence changes from four to three aspects.		
H	Start and finish points of bi-directional working.		
I	Stations where the signal is not in view from the station stopping point, with potential for starting against the signal at danger.		
J	Stations where the normal stopping point is adjacent to the signal with potential for starting against the signal at danger.		
K	Risks associated with trains not stopping at designated stopping points within a station platform.		

Hazard/Risk		Location & Detail
L	Potential distractions on approach to a signal, such as a neutral section.	
M	Locations or routes with a mixture of colour light and semaphore signalling.	
N	Locations or routes not fitted with Automatic Warning System (AWS), including termination and commencement points of AWS and AWS gaps.	
O	Low adhesion due to seasonal factors (including weather and leaf fall).	
P	Possibility of unexpected low adhesion conditions at level crossings and the consequential risk of wheel slide, particularly where hazards are located beyond the crossing (for example, high risk signals or stations with permissive working or bay platforms).	
Q	The effects of driving over the route in darkness compared with driving during the daytime.	
R	Lighting on platforms, in tunnels or adjacent streets which may affect the identification of braking points and sighting of signals.	
S	Locations that may cause distraction, such as depots and yards.	
T	Locations where bi-directional, reversible or multi track lines do not run parallel to each other.	
U	Locations where there is a significant reduction in line speed.	
V	Gradients that have the potential to affect safe train operations.	
W	Communication black spots.	
X	Complex signalling or track layouts.	
Y	Frequency Staff will work over a route once completed.	
Z	Locations that are fitted with overhead line equipment and the limits of electric traction movements.	

Appendix D – Incident Response - Roles and Responsibilities

The following roles are typical to an incident management structure. Generic responsibilities are also described below.

Role	Responsibilities
Executive	Ensure that the incident management structure conforms to the requirements of any internal processes and measures the performance.
Director responsible for incident management arrangements	Has the overall responsibility for the performance of the incident management structure to support company resilience arrangements
Senior manager responsible for incident management arrangements	To lead, develop and embed resilience arrangements, inclusive of emergency preparedness and response, crisis management and business continuity in line with its business, customer, and regulatory requirements. To carry out verification of the competency management system for the incident management structure.
Senior manager responsible for learning and development	To engage with the senior manager responsible for incident management arrangements to ensure that all competency-based training needs are addressed, and any training requests are validated and budgeted.
Manager responsible for documenting incident management arrangements	Responsible for delivering an effective and holistic major incident plan inclusive of all transport requirements, including the management of relevant plans and processes, including maintenance, reviewing and ongoing testing through exercising with partners. Ensures that all transport operations are fully compliant with requirements stipulated within relevant national and international legislation and regulatory frameworks.
Business Continuity Manager	To lead the creation, training, exercising, reviewing, and assessing business continuity processes/plans.
Resilience Officer	Supports the Resilience Team by supporting the delivery of an effective, timely and holistic corporate incident management and business continuity management provision inclusive of all business requirements.
Strategic Commander (Strategic/Gold)	To provide strategic leadership and set the strategic aim and objectives by considering the following: • Political factors • Economic or financial factors • Social factors • Technical factors

Role	Responsibilities
	• Environmental factors • Ethical factors • Legal or regulatory factors • Organizational factors • Safety • Security • Recovery
Tactical Commander (Tactical/Silver)	To invoke resilience arrangements and coordinate/manage the organizational response to a transport-related incident.
Operational Commander (Operational/Bronze)	To respond to resilience arrangements and coordinate operational resources to support the overall incident and provide engineering and operational, technical advice where needed. To act as the operational lead at the scene of a transport-related incident and manage the operational response for the organisation. This means acting as a liaison with the emergency services and the business to ensure an effective response and support function.
Duty Media Officer	To ascertain key media requirements and work with internal and external parties to provide media, communications and reputational management expertise, advice, and release media information/statements.
Duty Security and Resilience Advisor	To provide security and resilience advice and guidance and liaise/provide relevant information to key parties.
Licensing Advisor	To provide information and advice on transport packages and regulations.
Incident Support Officer	To support and assist the incident management structure in logging key decisions and actions and providing general support throughout the incident response.

NTS Strategic Risk Dashboard

RISK DESCRIPTION	Major safety or environmental incident caused by Rail operations (resulting in a derailment on the mainline network causing multiple fatalities, significant media coverage, legal action or loss of business. The cause of the incident as a result of deficiencies in maintenance, operational controls or infrastructure failures

Impact:	5 Severe	High 5	High 10	High 15	Extreme 20	Extreme 25
	4 Severe	Moderate 4	Moderate 8	High 12	Extreme 16	Extreme 20
	3 Major	Low 3	Moderate 6	Moderate 9	High 12	High 15
	2 Moderate	Very Low 2	Low 4	Moderate 6	Moderate 8	High 10
	1 Minor	Very Low 1	Very Low 2	Low 3	Low 4	Moderate 5
	Frequency: 0.01%	Frequency: 0.25%	Frequency: 0.50%	Frequency: 1.00%	Frequency: 2.00%	Frequency: 5.00%

	Risk Impact Category	Risk Rating	Risk Appetite
Safety		High 30	Low
Environmental		High 30	Medium
Legal		High 30	Medium
Reputation		High 30	Medium
Delivery		High 30	Medium
Security		High 30	Medium
Financial : DRS		High 30	Medium
Financial : IRS		Low 1	Medium

		Consequences		Likelihood
Key Impacts	Description		Consequences	Consequence
	1	Multiple fatality event		1 to 10
	2	loss of containment of cargo or fuel		1 to 10
	3	Damage to infrastructure		1 to 10
	4	loss of rolling stock		1 to 10
	5	inability to provide air customer service or line blockage preventing others from receiving a service		1 to 10
	6	regulator involvement		1 to 10
	7	legal action		1 to 10
	8			
	9			
	10			
	11			
	12			
	13			
14				

Existing Control: Impacts						Improvement Actions						
No.	Description	Cause	Mitigation	Risk Rating		No.	Description	Cause	Priority	Residual	Control	Completion
1	Close call reporting P0302 & P0701	DSE		Self-Assessment			Improve reporting and action culture in Rail - plan to be developed	JN	Medium			
2	Emergency Response P0422, P0804, PROM065, PROM047	Security		Self-Assessment								
3	Oil spill arrangements PROM093, PROM065	Security		Self-Assessment								
4	Getcha data, HAAD information from WWR and industry rail events	H&O					Improve the oversight of the industry data - plan to be developed	CP	Medium			
5	Investigation programme to identify root cause and set suitable actions to prevent reoccurrence	HSEQ										
6	Return to service checks P0704, P0302	Engineering		Self-Assessment								
7												
8												
9												
10												

Appendix G – Preliminary Transportation Plan



NUCLEAR WASTE
MANAGEMENT
ORGANIZATION

SOCIÉTÉ DE GESTION
DES DÉCHETS
NUCLÉAIRES

Preliminary transportation plan

December 2021

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Introduction to the NWMO

For more than 50 years, Canada has been using nuclear power as a reliable energy source to power our homes, businesses, schools, and hospitals. The Nuclear Waste Management Organization (NWMO) plays an important role that completes the fuel cycle. We are responsible for implementing, collaboratively with Canadians and Indigenous peoples (First Nations, Métis and Inuit), Canada's plan for the safe, long-term management of used nuclear fuel, in a manner that protects both people and the environment.

Canadian used nuclear fuel – a byproduct of nuclear power – is a stable solid that comes in the form of a fuel bundle and is not flammable or explosive. Currently, used nuclear fuel is stored at licensed interim storage facilities in Canada. This is a safe, but temporary solution. Canadians have made it clear that it is important to implement a long-term approach – and not leave it for future generations.

Canada's plan, also known as Adaptive Phased Management, calls for used nuclear fuel to be contained and isolated in a deep geological repository, a system of naturally occurring and engineered barriers, in an area with informed and willing hosts. A deep geological repository is a national environmental infrastructure project, aligns with international best practice, and benefits from the best available science and research, including Indigenous Knowledge.

After gradually narrowing our focus based on social and technical studies, there are currently two remaining potential siting areas involved in the NWMO's site selection process: the Ignace area in northwestern Ontario, and South Bruce in southern Ontario. We expect to select a single, preferred site in 2023.

A key component of Canada's plan is transporting used nuclear fuel to the deep geological repository site. Transportation will begin in the 2040s – once the repository is operational.

Globally, the transportation of used nuclear fuel has a strong record of safety. Over 50 years, there have been more than 20,000 shipments worldwide of used nuclear fuel, and none have caused harm to people or the environment because of the release of radioactive materials. There is also a strong regulatory framework for the transportation of used nuclear fuel. Transportation of used nuclear fuel in Canada is regulated by the Canadian Nuclear Safety Commission (CNSC) and Transport Canada. Shipments will also meet the International Atomic Energy Agency (IAEA) safeguard requirements to ensure they are safe and secure.

The NWMO's highest priority as we plan for transportation is safety. Safety is at the core of everything we do at the NWMO, as our overriding objective is the protection of people and the environment. Based on conversations with thousands of Canadians and Indigenous peoples, we understand that people have questions and concerns about the transportation of used nuclear fuel. The NWMO is committed to an ongoing dialogue with Canadians and Indigenous peoples as we refine our transportation plans. Public input is invaluable to this process. Together, we are setting priorities, principles and objectives for transportation planning, which can be found on our website at www.nwmo.ca/transportationplanning. This plan is an early step in the NWMO's Transportation Planning Framework. The goal of this document is to begin to answer the questions we are hearing about transporting used nuclear fuel in the 2040s. It outlines the multiple layers of safety that are required through the regulatory framework and additional measures that the NWMO plans to put in place.

This transportation plan is preliminary in nature given a few factors, including:

- » Two siting areas remain in the NWMO's voluntary site selection process;
- » The NWMO is considering two modes of transportation – an all-road system and a road/rail system; and
- » Technology, infrastructure, best practices, and societal priorities are expected to evolve over the 20-year planning time frame.

We recognize that this preliminary plan will evolve and become more detailed over the next 20 years. Future work planned for upcoming years will be included in subsequent iterations of this plan. This plan has three sections:

Section 1: Overview of the transportation program. This section provides information about the NWMO's preliminary transportation system designs and answers commonly asked questions about how the NWMO plans to transport used nuclear fuel.

Section 2: Safety and security. This section describes commonly raised concerns about transportation safety, regulatory requirements for safely transporting used nuclear fuel, as well as the multiple layers of safety the NWMO will apply to our transportation program.

Section 3: The road ahead. This section describes planned work over the upcoming years to further inform and refine our transportation planning.

1. Overview of the transportation program

People have asked us many questions about how the NWMO plans to transport used nuclear fuel. The map below shows the locations of interim storage facilities and the two potential sites, providing a sense of the scope of this transportation program and understanding that the used nuclear fuel must be transported through communities and traditional territories to whichever site is selected. The transportation program is expected to begin in the early 2040s once the deep geological repository is operational and take up to 50 years to complete.

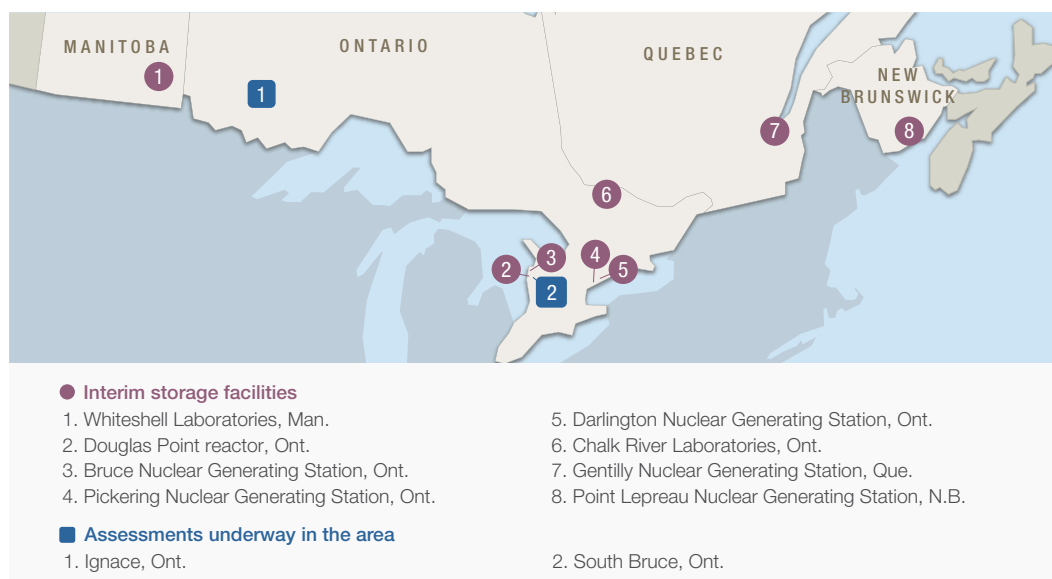
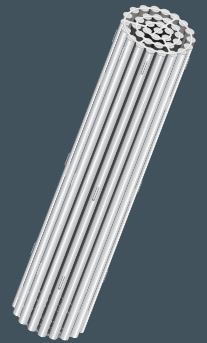
Acknowledging the preliminary nature of this plan, the following section outlines the NWMO's current thinking on how this transportation program will be approached. We are looking at two options for each site, either:

- 1) An all-road used fuel transportation system; or
- 2) A road/rail used fuel transportation system.

For planning purposes, the all-road used fuel transportation system is referred to as the NWMO's reference case. This is the option that is considered for lifecycle cost estimates to ensure accountability and transparency as we implement Canada's plan. The road/rail used fuel transportation system is referred to as the alternative case. Both transportation mode options can be safely implemented to either potential repository site. The designs for these two systems have been established and consider the following: regulatory requirements; the use of various transportation packages; potential vehicles (e.g., trucks/rail cars); associated fleet requirements for transport packages; representative routes; nuclear security and escort arrangements; emergency management, including response and recovery; logistics and scheduling of shipments; as well as operational aspects such as communication, monitoring and tracking of shipments.

Once a site is selected, the NWMO, in collaboration with Canadians and Indigenous peoples, will confirm the NWMO's used fuel transportation system, which will include finalizing key decisions such as the selection of transport mode(s) and packages. Based on these decisions, the design of a used fuel transportation system will be refined and provide the foundation for future work.

Used CANDU nuclear fuel (the fuel used by Canadian reactors) is not a liquid or a gas – it is a solid. It is not flammable, fissile or explosive.



1.1 How many used fuel bundles will there be?

As of June 30, 2021, there are approximately 3.1 million used fuel bundles in storage at the eight interim storage facilities in Canada. By the end of the operating life of each of Canada's existing nuclear reactors, it is anticipated that there will be 5.5 million used fuel bundles. The table below outlines how much used nuclear fuel is stored at each interim storage facility and the projected number of packages that would be transported from each facility over the 50-year time frame over which operations will be ongoing. It is important to note that while Whiteshell is identified as an interim storage facility on the previous map, the NWMO anticipates that the used fuel bundles at this facility will be consolidated with the used fuel bundles at Chalk River, based on current decommissioning plans for the Whiteshell facility.

Interim storage facility	Origin site	Projected number of used fuel bundles to be transported	Projected number of transportation packages to be transported (all road)	Projected number of transportation packages to be transported (road/rail)
Bruce	Bruce	2,907,650	15,147	7,573
Pickering	Pickering	902,148	4,699	2,350
Darlington	Darlington	1,268,801	6,610	3,305
Chalk River	Chalk River	7,187	90	90
Douglas Point	Bruce	22,256	207	207
Gentilly-1	Gentilly	3,213	43	43
Gentilly-2	Gentilly	129,925	1,083	1,083
Point Lepreau	Point Lepreau	258,820	2,157	2,157
Totals:		5,500,000	30,036	16,808

Q&A

Will the NWMO be responsible for used fuel from small modular reactors? Will this increase the amount of used fuel? If so, how will those be transported?

As mandated in the *Nuclear Fuel Waste Act*, the NWMO is responsible for all Canada's used nuclear fuel – including that created using new or emerging technologies like small modular reactors. This means that used fuel could be transported from any province that chooses to pursue the use of small modular reactors, including those west of Manitoba. Canada's plan will be implemented over several decades, and a fundamental tenet is incorporating new knowledge and technical advancements. The NWMO has outlined criteria that any fuel waste will need to meet to ensure it be accepted, and this includes transportation requirements. Regardless of the type of used fuel we are transporting (conventional reactors or small modular reactors), the stringent regulatory requirements for transportation will be applied to the NWMO's transportation program – see the following pages for more information. For more information about Canada's Small Modular Reactor Action Plan, please go to www.nrcan.gc.ca/our-natural-resources/energy-sources-distribution/nuclear-energy-uranium/canadas-small-nuclear-reactor-action-plan/21183.

1.2 How will it be transported?

Transportation packages

Safety of transporting used nuclear fuel begins with transportation package design. Transportation of used nuclear fuel will occur in a certified package that adheres to stringent Canadian regulations and international standards. Used nuclear fuel transportation packages are designed and tested to ensure protection of people and the environment during normal operations, as well as during severe accident conditions – even though unlikely.

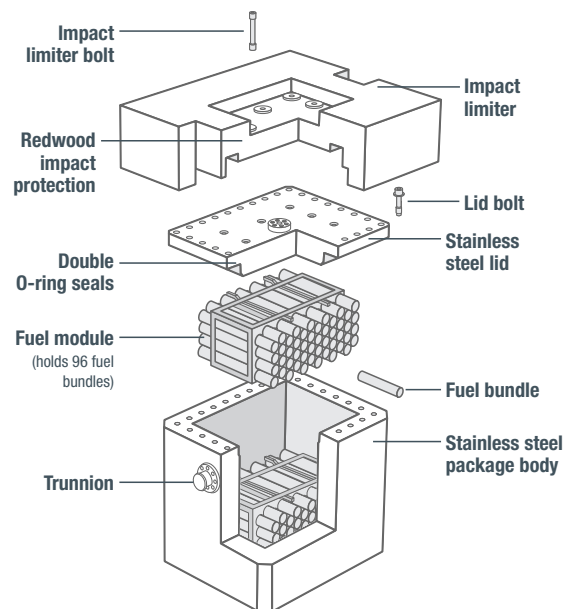
The CNSC regulations are aligned with international standards, and the CNSC is responsible for evaluating transportation packages and certifying designs. Before a used nuclear fuel transportation package can be used in Canada, the design must be reviewed and certified by the CNSC.

The NWMO is assessing different package designs for transporting used nuclear fuel. Final designs will be selected based on a number of factors such as how the used fuel is currently stored, transportation modes, and efficiency. To minimize handling during the transfer from interim storage to the transportation package, the NWMO is looking at using transportation packages that accommodate the current storage method.

Used fuel from Ontario Power Generation (OPG)-owned sites (Bruce, Pickering and Darlington) is currently stored in in rectangular fuel modules (see diagrams that follow) contained in dry storage containers. For fuel that uses this storage method, there are two existing transportation package designs that the NWMO is exploring:

Used Fuel Transportation Package

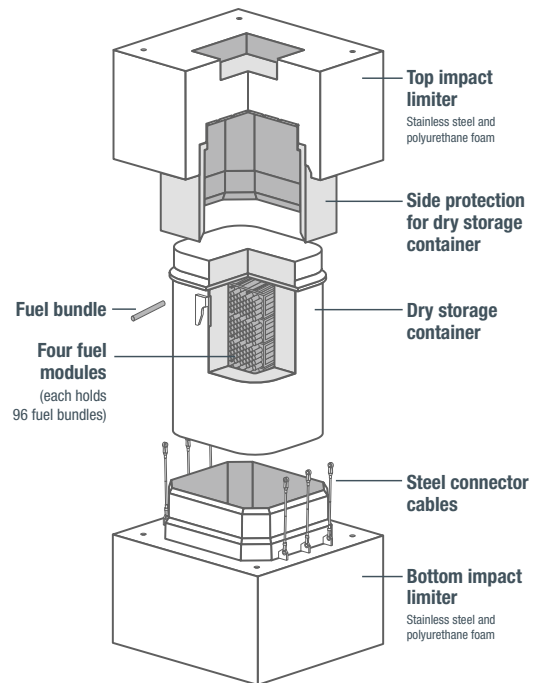
The Used Fuel Transportation Package (UFTP) consists of three main components: the body, lid and impact limiter. The body and lid are made of solid stainless steel with walls nearly 30 centimetres thick. The lid is attached to the body by 32 bolts. The impact limiter consists of a redwood core encased in a stainless steel skin. The stainless steel body and lid provide containment, shielding and impact resistance. The impact limiter is designed to protect the body and lid closure in the event of an accident. The reusable package can carry 192 used fuel bundles (two modules) and weighs almost 35 tonnes when loaded.



Dry Storage Container Transportation Package

Used nuclear fuel is currently stored on an interim basis in dry storage containers (DSC) at OPG Waste Management Facilities. The Dry Storage Container Transportation Package (DSC-TP) consists of a DSC fitted with impact limiters on each end.

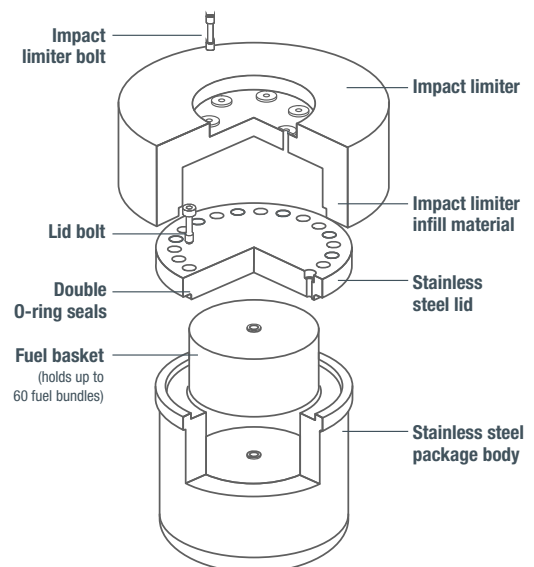
The DSC consists of a body and lid made of high-density concrete encased in a carbon steel skin. The DSC body and lid are welded closed after being filled with used fuel. The reusable impact limiters consist of stainless steel shells filled with rigid polyurethane foam. The impact limiters are fastened together using steel cables. The DSC provides containment and shielding, and the impact limiters are designed to protect the DSC in the event of an accident. The DSC can carry 384 used fuel bundles (four modules) and weighs approximately 100 tonnes when loaded.



All other used fuel (Point Lepreau, Gentilly, Chalk River, Whiteshell, and Douglas Point) is currently stored in dry storage baskets. For fuel that currently uses this storage method, the NWMO is exploring the development of the following transportation package design:

Basket Transportation Package

The Basket Transportation Package (BTP) is under development and designed to move used fuel that is currently stored in dry storage baskets. The BTP consists of the following main components: body, lid, and one or two impact limiter(s). The image on the right shows the BTP concept with one impact limiter. Impact limiters are designed to protect the BTP in the event of an accident. This reusable package can carry up to 120 used fuel bundles (two baskets) and is anticipated to weigh 28 tonnes when loaded.

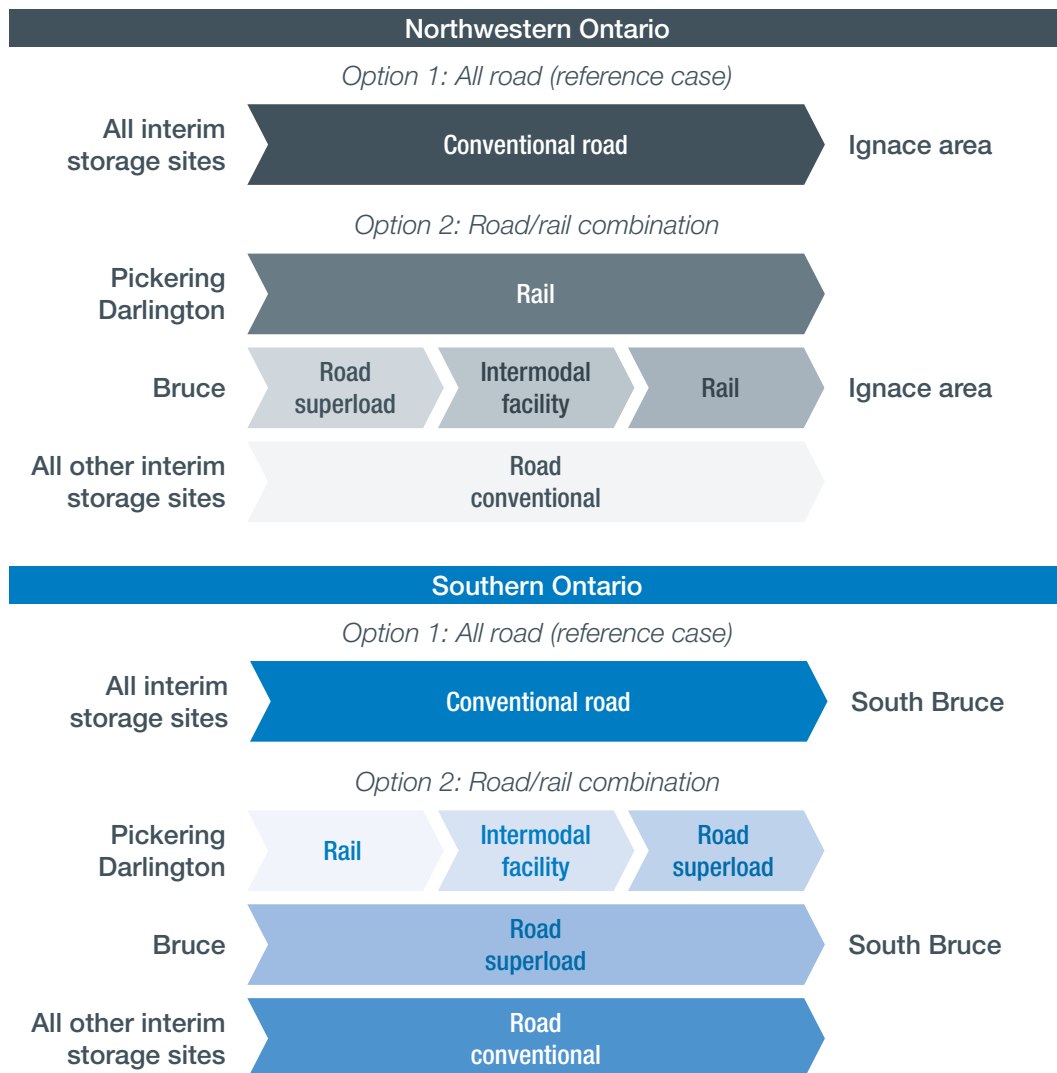


Transportation modes

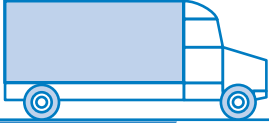
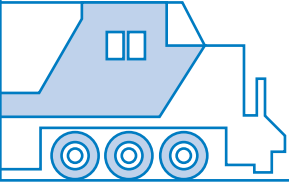
The transportation systems being considered assume the predominant use of existing infrastructure; however, some local site infrastructure will be required. As described above, the NWMO's two systems under consideration include an all-road option and a road/rail option to each potential host site.

Defining these options helps the NWMO develop preliminary routes, make early assumptions about infrastructure that will be needed to support the transportation program and assist in resource planning. For example, road/rail options to each site will require superload shipments and the development of an intermodal facility. Superload shipments are heavy haul shipments that require special permits to transport because of their weight. This would involve the movement of an entire Dry Storage Container (100 tonnes) a relatively short distance (e.g., from Bruce Power to the South Bruce site, or from Bruce Power to a rail line for the Ignace area site). An intermodal facility would allow for the safe and secure transfer of used fuel from truck to train or vice versa. The diagrams that follow describe these options in more detail, as well as what transportation package designs would be used in each mode.

Although the all-road and road/rail systems are shown for each potential siting area, the road/rail option may not make sense for both sites. For example, there is no existing rail infrastructure to the South Bruce site, which makes Option 2 for southern Ontario, in particular, an unlikely choice. For this reason, our preliminary planning has focused predominantly on the all-road options, known as the reference case.



All road (reference case)	Both sites
Truck	
	576 UFTPs/year – 1 package/truck 78 BTPs/year – 1 package/truck
Total: 654 shipments/year	

Road/rail alternative	South Bruce	Ignace area
Truck		
	78 BTPs/year 1 package/truck	78 BTPs/year 1 package/truck
Superloads		
	288 DSC-TPs/year 1 package/truck	165 DSC-TPs/year 1 package/truck
Rail		
	25 DSC-TPs/year 5 packages/train	22 DSC-TPs/year 14 packages/train
Total: 391 shipments/year		Total: 265 shipments/year

Why is the NWMO looking at two transportation mode options – either an all-road system, or a road/rail combination system?

There are a number of factors to consider when it comes to transportation mode selection. Both transportation mode options – an all-road system or a road/rail combination system – can be safely implemented to either potential repository site. Other factors that will be taken into account include transportation package designs, existing infrastructure, and operational elements like scheduling and routing. As identified above, and based on these factors, the all-road system is the NWMO's reference case, and a road/rail system is an unlikely option for the South Bruce site.

For current planning purposes, the all-road transportation system (reference case) makes use of two package designs – the UFTP and BTP – both of which are suitable for transport over existing highway networks using conventional tractor-trailers based on approximate weights and dimensions.

The all-road transportation system uses existing highway networks and provides more flexibility in terms of scheduling and routing. This option would result in a higher number of overall shipments per year because the UFTP and BTP are transported individually (one per tractor-trailer), while multiple packages can be transported at once by rail.

The road/rail combination system also uses two package designs – the DSC-TP and the BTP. While the BTP can be transported over existing highway networks in a conventional tractor-trailer, the DSC-TP requires a specialized superload truck and is subject to additional restrictions due to its weight and overall dimensions. These may include lower speed limits, use of additional escort vehicles, and lower scheduling flexibility.

Because of these restrictions, it is more efficient to transport multiple DSC-TPs at a time using rail rather than individually over road, whenever possible. This option would result in a lower number of overall shipments per year, with each shipment carrying a higher number of used fuel bundles when compared to the all-road system.

Are all transportation packages (the UFTP, DSC-TP and BTP) currently certified in Canada?

The NWMO currently holds a design approval certificate for the UFTP. If the DSC-TP is used, it may need some additional work to ensure that it is certified for road and rail transport. The BTP would need to go through the certification process if the NWMO decides to proceed with this design.

Why doesn't the NWMO just use the UFTP – especially if it is already certified?

Used fuel bundles are packaged in different ways at different interim storage facilities. To minimize handling, the NWMO is proposing to use certified transportation packages that accommodate the current storage method.

How would the NWMO transport a superload and why?

The use of superloads is being considered for relatively short distances (typically less than 125 kilometres) as part of the road/rail alternative due to the weight of the package. A superload would involve the movement of a full DSC, which can carry 384 used fuel bundles (compared to the 192 bundles held by the UFTP). Superloads would be used to minimize the number of times used fuel bundles are handled because the used fuel can be moved in the package in which it is currently stored at interim storage facilities.

1.3 What distances will be travelled?

The distances from the interim storage facilities to each potential repository site are described below. For road shipments from all locations, transport teams consisting of two drivers in the vehicle (one off-duty, one on-duty) are assumed for the entire round trip. There are exceptions to the two-driver teams where distances are relatively short. The asterisks in the table below indicate shipments that would be completed by a single driver.

Potential deep geological repository location	Interim storage facility/ Projected used fuel bundles	All road (reference case)	Road/rail alternative	
		One-way road distance (km) ¹	Road distance (km)	Rail distance (km)
Northwestern Ontario (Crystalline – Ignace area)	Bruce (2,907,650)	1,775	125*	1,750
	Pickering (902,148)	1,725	-	1,600
	Darlington (1,268,801)	1,725	-	1,625
	Point Lepreau (258,820)	2,900	2,900	-
	Chalk River (7,187)	1,600	1,600	-
	Gentilly-1 (3,213)	2,150	2,150	-
	Gentilly-2 (129,925)	2,150	2,150	-
	Douglas Point (22,256)	1,775	1,775	-
Southern Ontario (Sedimentary – South Bruce)	Bruce (2,907,650)	50*	50*	-
	Pickering (902,148)	275*	75*	225
	Darlington (1,268,801)	300*	75*	250
	Point Lepreau (258,820)	1,725	1,725	-
	Chalk River (7,187)	600	600	-
	Gentilly-1 (3,213)	950	950	-
	Gentilly-2 (129,925)	950	950	-
	Douglas Point (22,256)	50*	50*	-

¹ Distances are rounded to the nearest multiple of 25 kilometres.

* Shipments completed by a single driver.

The northwestern Ontario site is obviously farther from the interim storage facilities – why is the NWMO considering a site that is so far away – doesn't this increase the risk of transportation accidents?

For a site to be selected, the NWMO will need to demonstrate the following:

- 1) A deep geological repository can be safely implemented with a strong technical safety case;
- 2) The project can be implemented in partnership with informed and willing hosts; and
- 3) Confidence that a safe, secure and socially acceptable transportation plan can be developed.

Section 2 of this document describes the safety controls the NWMO will implement to ensure safe transportation of used nuclear fuel regardless of the location of the repository site. These controls have enabled countries around the world to safely transport used nuclear fuel for over 50 years without an accident leading to human or environmental harm because of radioactive release.

The NWMO is confident in the safety of transportation to either site.

1.4 What are the time frames for transporting used fuel?

The transportation program is expected to take up to 50 years to complete. This will involve transportation of the used nuclear fuel from different interim storage facilities at different times.

The timing of the shipments will be based on the site's ability to receive and repackage the used fuel and place it into the deep geological repository. The table below describes approximate time frames for moving the used nuclear fuel from the interim storage sites to whichever host site is selected. Transport from some interim storage facilities will overlap. The time frames below consider that transportation year-round is not always feasible due to weather, potential road restrictions and other unknowns (e.g., equipment downtime, maintenance, etc.).

At this early conceptual design stage and for costing purposes, the time frames assume that shipments will occur six days per week for about nine to 11 months of the year. These assumptions depend on which site is selected.

Interim storage facility	Time frames (approximate years)
Bruce	35-50
Pickering	5-20
Darlington	20-45
Point Lepreau	10-15
Chalk River	1
Gentilly-1	1
Gentilly-2	1-5
Douglas Point	1-5

If there is more used fuel than is currently anticipated, does this mean there will be more shipments per year?

No. The pace of shipments is determined by the rate that the NWMO can repackage the used fuel bundles and place them in the repository, not the total number of used fuel bundles. Annual shipments would only increase if operational efficiencies are found in the repackaging process at the deep geological repository site.

Has the NWMO determined the order in which it will remove the used fuel from the interim storage facilities? Which interim storage facility will be first?

The order of shipments has not been finalized. This will be based on considerations such as the number of used fuel bundles in each location, the age of the used fuel being stored, and the operational status of the interim storage facility.

You say that you assume that shipments will run about nine to 11 months of the year. Does that mean that you won't run shipments between January and March?

No. Shipments will be dependent on the conditions identified above (weather, road restrictions and unscheduled maintenance). In this conceptual design phase, we are conservatively assuming that for about 30 to 90 days of the year, we may not be able to transport used fuel due to these conditions.

1.5 What equipment will we need?

Whichever type of transportation package is required, specialized equipment will be needed to transport these packages.

Road transport: Transport trucks will include various features to ensure the safe and secure movement of used nuclear fuel. The transport tractor must have an engine capable of pulling a combined load of the trailer and when fully loaded – for conventional trucks, weights are similar to that of a logging truck. In addition to the engine power requirements, trucks or trains will have many other equipment features. The NWMO will continue to investigate new and evolving best practices in equipment and technology over the next 20 years. At this point in time, example equipment features could include:

- » Extended cab with an integrated sleeper berth;
- » Speed limiters to meet provincial regulations;
- » Radar-based collision mitigation system to assist drivers with avoiding collisions;
- » Anti-theft electronic immobilizer system (e.g., biometric or handprint scanner);
- » Passenger mounted LCD touch screen computer with GPS interface for communications with the Transportation Communication & Control Centre (C&CC);
- » Fire extinguishing/suppression equipment to meet the National Fire Code;
- » Cellular and/or satellite phone;
- » Event recorders and onboard video cameras;
- » Anti-lock braking system (ABS) brakes;
- » Ride and stability control with self-steering axles;
- » Custom-designed mounting frame to spread the load of the transportation package evenly across the axles;
- » Transportation package tie-down system;
- » GPS units for remote real-time tracking of the vehicle location (one on the tractor and one on the transportation package carried within the trailer); and
- » Emergency response personal protective equipment.

Rail transport: Transport by rail is expected to include the following features:

- » LCD touch screen computer with GPS interface for communications with repository site central logistics team;
- » Fire extinguishing/suppression equipment to meet the National Fire Code;
- » Cellular and/or satellite phone;
- » Event recorders and onboard video cameras;
- » GPS units on each locomotive and railcar for remote real-time tracking of the vehicle location; and
- » Emergency Response Personal Protective Equipment.

Canadian regulations established by the CNSC and Transport Canada require the maintenance, testing and inspection programs and associated schedules for performing repairs and maintenance activities on transportation security systems, technical devices and equipment.

2. Safety and security

There is a strong regulatory framework for the transportation of radioactive materials at both a national and international level. Transportation of used nuclear fuel in Canada is regulated by the CNSC and Transport Canada. Shipments will also meet the IAEA safeguard requirements to ensure they are safe and secure. Transportation operations will meet federal, provincial and local safety legal requirements, and will be inspected for compliance. The NWMO will need to demonstrate to regulatory authorities the safety and security of a transportation system before the shipments of used fuel can begin.

The section below describes aspects of the regulatory framework that focus on safety and security, as well as the NWMO's multi-layered approach to transportation safety. That said, the NWMO recognizes and acknowledges that people have had different lived experiences with transportation and may have additional questions about safety. We recognize there is a difference between regulatory safety and social safety. We will begin this section with a discussion of social safety.

2.1 Public priorities – Social safety

First and foremost, it is the NWMO's responsibility to protect people and the environment. This begins with understanding what people are concerned about and considering whether and how our program addresses these concerns. We have heard from the public that they are concerned about the risks associated with transportation. These concerns are often expressed in the description of potential accident scenarios and questions about whether the transportation packages could withstand those specific accident scenarios. To address common concerns raised, some of these accident scenarios are described in the table below. Next to each scenario is a reference to the section of this plan that describes how the NWMO will either mitigate or respond to such scenarios, along with a description of how the NWMO plans to protect people and the environment from all accident scenarios.

Scenarios		Section reference
1	Accident involving the release of solid used fuel bundles into water	Sections 2.3.1 and 2.3.3
2	Road or rail accidents involving multiple points of impact (e.g., package rolls down a rockface into a river)	Sections 2.3.1 and 2.3.3
3	Road or rail accidents due to bad weather (e.g., snow, freezing rain)	Sections 2.3.2 and 2.3.3
4	Natural disaster events along transportation routes (e.g., flood, fire, rockslide)	Sections 2.3.2 and 2.3.3
5	Road or rail accidents requiring volunteer first responders	Section 2.3.3
6	Train derailments in remote areas	Section 2.3.3
7	Transportation package being the target for terrorist activity	Section 2.3.3

2.2 Regulatory safety

As previously mentioned, there is a strong regulatory framework for the transportation of used nuclear fuel in Canada.

Consistent with this framework of regulation and oversight, the NWMO's transportation program will need to meet the CNSC's and Transport Canada's requirements to be approved. Below is an overview of different aspects of our program and specific regulations.

Transportation package: Used nuclear fuel transportation packages are designed and tested to ensure protection of the public during normal operations, as well as during accident conditions. The CNSC, using internationally recognized standards that have been in existence for over 60 years, has the responsibility for evaluating the transportation package and certifying its design, the registration of the use of individual packages, and monitoring the package maintenance process. These standards are set by the IAEA under *Regulations for the Safe Transport of Radioactive Material – Specific Safety Requirements* (No. SSR-6).

Prior to transporting used nuclear fuel in Canada, the CNSC's comprehensive regulatory framework requires a certificate for the transport package and a licence to transport. The CNSC evaluates applications to ensure that safety and security measures are technically and scientifically sound, that all requirements are met, and that the appropriate safety and security provisions are in place to protect people and the environment. Packages used to transport used nuclear fuel from interim storage facilities to the repository must be certified by the CNSC.

Radiological safety: Packages used to transport used nuclear fuel must meet radiation level requirements prescribed by the CNSC's *Packaging and Transport of Nuclear Substances Regulations*, 2015. Regulatory requirements for the package ensure the public and workers are safe. The package is designed and tested to ensure that in the event of an accident, any radiological release will not exceed the regulatory limits. The CNSC's *Radiation Protection Regulations* have set an annual radiation dose limit for members of the public to limit exposure from nuclear-related activities, using the ALARA principle (As Low As Reasonably Achievable).

Emergency response and training: Transport Canada's *Transportation of Dangerous Goods Regulations* establish requirements for worker and driver training, emergency planning, safety marks (e.g., placards), and documentation. Emergency response planning will be required through the CNSC licence conditions as well. Transportation planning needs to address these aspects and ensure that all equipment, packages and activities for road and rail shipments meet regulatory requirements. The NWMO will need to demonstrate that all activities will be conducted by trained personnel, including emergency responders. The NWMO will also need to develop an emergency response plan and ensure workers and emergency responders are trained before shipments can begin.

Security: Security provisions during transportation need to ensure CNSC regulatory requirements are met. Security measures are aimed at preventing diversion or sabotage of the transportation package, and include a combination of engineered, physical and monitoring measures to protect the cargo, and provide for detection, alarm, recording, and communication, in the event of an occurrence.

2.3 The NWMO's safety program

Based on the strong regulatory framework described above, the NWMO's program has multiple layers of safety.



2.3.1 The transportation package

Scenario 1

Cumulative effects testing addresses concerns about multiple impact accident scenarios.

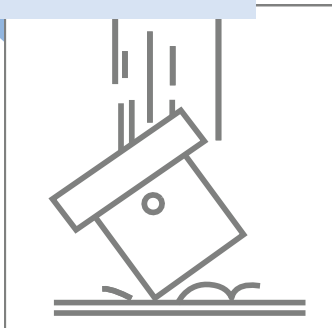
Safety is built into every element of the NWMO's transportation program, beginning with the transportation package design. Used nuclear fuel transportation packages are designed and tested to ensure protection of the public during normal operations, as well as during accident conditions.

Before a used fuel transportation package can be used in Canada, the design must be certified by the CNSC to meet regulatory requirements, which incorporate international safety standards. The requirements include tests designed to demonstrate the ability of the package to withstand severe impact, fire and immersion in water. These are extreme tests to demonstrate how durable packages are.

When all the requirements for design and testing are met, the CNSC issues a certificate for the package design. The certificate specifies instructions for the operation and maintenance of the transportation package. It also defines the authorized contents that may be carried in the package. The certificate is typically valid for five years. At the end of this period, the NWMO will have to reapply to re-certify the package.

To gauge the cumulative effects on the transportation package design, the first two tests described below are conducted in the sequence that would result in the most damage to the package, followed by the thermal test. For more information about transportation package testing and regulations, go to www.nwmo.ca/transportation.

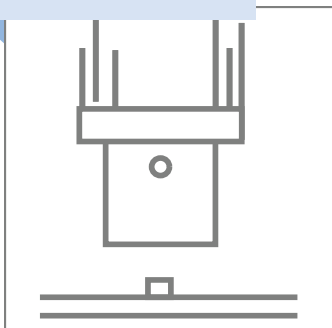
Free-drop test



The package is dropped from nine metres (30 feet) onto a flat, unyielding surface (such as a steel-reinforced concrete pad), striking the surface in the orientation that will result in the most damage to the package.

This test determines the performance of the package when it experiences loads comparable to the most severe potential transportation collision. The loads associated with this test are many times higher than those experienced when a train travelling at 160 kilometres an hour collides with the transportation package. A detailed analysis is available in the NWMO technical report: *Why the Nine Metre Drop Test Bounds the Impacts from Most Severe Accidents* (NWMO TR-2014-04).

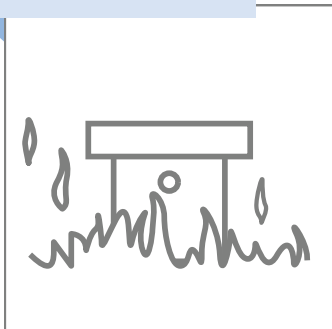
Puncture test



After the drop test, the same package is subjected to a one-metre (40-inch) free drop onto a 15-centimetre (six-inch) diameter steel bar at least 20 centimetres (eight inches) long.

While the free-drop test simulates an impact that is spread over a larger area, this test looks at what would happen in a collision with a sharp object. The test demonstrates that the container will not puncture.

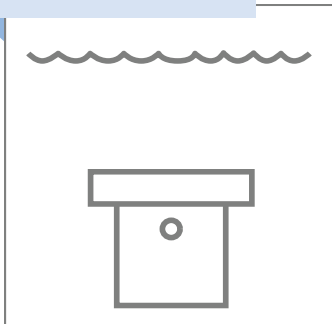
Thermal test



Using either computer analysis or physical testing methods, the same package used in the drop and puncture tests is then subjected to a fully engulfing petroleum fire. The fire temperature must reach 800 degrees Celsius (1,475 degrees Fahrenheit) for 30 minutes.

This test mimics the conditions of a potential severe accident involving flammable liquids near a package. The fire must fully engulf the package for the entire test. The flame must reach 800 degrees Celsius, which is typical of a hydrocarbon fire. In real accidents, fires involving flammable liquids generally do not burn for 30 minutes because the supply of fuel dwindles and the fire location shifts.

Immersion test



Using either computer analysis or physical testing methods, the package is subjected to external pressure that is the same as if it were immersed under 15 metres (50 feet) of water for at least eight hours to test for leakage. The package is also subjected to an enhanced water immersion test at 200 metres (650 feet) to test its ability to withstand extreme external pressures.

Water bodies near most bridges, roadways or harbours are less than 15 metres deep. The eight-hour period is sufficient to allow the submerged package to come to a state where its conditions will not change, regardless of the length of time required to remove it. The enhanced immersion test (200 metres) considers the unlikely possibility of a package sinking at particularly deep locations, such as some points on the continental shelf. It subjects the package to maximum pressure.

Scenario 2

This Q&A addresses concerns about release of package contents into water.

What if the transportation package opens and a fuel bundle or pellet gets into the water?

Firstly, in the over 50-year history of transporting used nuclear fuel internationally and in Canada, there has never been a transportation package damaged to the point where radiological release has resulted in human or environmental harm. This is because of the stringent regulations in place and the robust package design.

Transportation packages are designed and tested to withstand severe accident conditions, and offer a very high degree of assurance that a package cannot be breached. The tests required by the CNSC are described on p. 20. Additional examples of extreme accident scenarios (e.g., a train running into a package at 160 km/hr or a propane tank rail car exploding beside a package) can be found on our YouTube channel at www.youtube.com/NWMOCanada.

In any accident scenario, procedures outlined in the transportation emergency response plan would be followed. The plan would detail the response actions that should take place, resources available to mitigate the situation, and ultimately, how to return the accident site to normal.

If there was an accident and the package fell into water, the most likely result would be no release of radioactivity. Even so, the NWMO has heard that people are interested in understanding more about the implications of these types of extreme accident scenarios. As described in Section 3, the NWMO's future work will include more detailed studies of accident scenarios, including assessing potential radiological doses to members of the public and workers in these very unlikely events.

It is important to note that used nuclear fuel is a stable solid – not a liquid or a gas, and it is not flammable or explosive. Because of this, it also does not readily react or break down in water. This means that even in the virtually impossible scenario that a container was somehow breached, widespread contamination would also be very unlikely.

2.3.2 Operational safety

The next layer of safety applied to the transportation system is the operational controls layer. These are the actions the NWMO will take to prevent accidents and manage risks, including route selection, communications, and real-time monitoring and tracking. Most importantly, if an event is detected along the transportation route in advance of a transportation shipment, such as bad weather or a highway closure, the shipment will not go out or an alternate route will be used (depending on the situation).

Route selection

Safety will be the top factor when it comes to transportation route selection. Other priorities such as fastest routes and highest quality infrastructure will also be considered. Route assessments will be guided by:

- » Minimizing the total time that the nuclear material remains in transport;
- » Minimizing the number and duration of any transfers of the nuclear material from one vehicle to another;
- » Avoiding fixed transport schedules for the movement of the nuclear material;
- » Varying the routes used to transport the nuclear material, considering applicable regulations and ordinances regarding transport routes for radioactive and hazardous materials; and
- » Choosing routes that consider any obvious hazards such as rockslides, floods or forest fires that could adversely affect the transport at certain times.

In addition to the regulatory requirements, the NWMO's route selection will also be guided by:

- » Seasonal load capacity restrictions on travelled roadways (for road transport);
- » Load height and weight restrictions (road and rail); and
- » Potential emergency response times (for road and rail).

In addition to the above variables, the NWMO's dialogues with Canadians and Indigenous peoples have provided another set of considerations for routing that the NWMO will continue to review as work progresses. Some of these are covered above. Other considerations include:

- » Proximity to population centres and schools;
- » Proximity to sensitive environmental areas (e.g., for any new infrastructure required);
- » Potential need to improve existing or build new infrastructure (e.g., extension of rail track);
- » Potential for traffic congestion and potential impact on commuters;
- » Assessment of political and social acceptance;
- » Trade-off between a longer route that goes through less densely populated areas versus a shorter route that goes through more densely populated areas; and
- » Indigenous and local knowledge of specific corridors.

The NWMO will continue to work with Canadians and Indigenous peoples to explore priorities and considerations related to route selection as transportation planning evolves and becomes more refined once a site is selected.

What transportation routes are being considered? Why hasn't the NWMO published these?

Current regulations do not allow the public disclosure of security information on the location, routes and timing of shipments, nor any security arrangements or procedures specific to the transportation of used nuclear fuel. This type of information is considered prescribed and is limited to persons who have a legitimate need to know, such as police response forces.

That said, we recognize that many of the potential routes are obvious. Also, we know that people are interested in giving us feedback about factors they think we should consider for route selection. This is valuable information for us. In fact, the considerations that people have given us to date are being included in our ongoing routing analysis.

Because there are still two sites and we are still looking at road, or a combination of road and rail in terms of modes, there are many potential routes that are being considered. These routes would, for the most part, be along transport infrastructure currently in use for the transportation of dangerous goods and the many other radioactive shipments that are being transported in Canada every day. To get a bit more specific, routes will be predominantly along major provincial highways and/or Class 1 rail lines.

We will continue to bring more information about routing considerations as we work through routing analysis, including information that can be shared from a regulatory perspective.

More information about transportation of used nuclear fuel can be found at <https://nuclearsafety.gc.ca/eng/resources/fact-sheets/packaging-and-transport-of-nuclear-substances.cfm#F5>.

Communications

During transportation, the drivers will remain in frequent contact with the shipper, receiver, local authorities, and response forces along the transport route. For security reasons, communication will be by encrypted messages only.

In remote regions, there may be gaps in communications coverage. Where it may not be possible to avoid such “blackout” areas along the transport route, other communication arrangements will be established. Satellite telephones can be used as backup communications in the event of disruption of primary cellular communications.

Additionally, the NWMO will review new communication technologies for use as they are proven reliable. Example equipment:

- » CB radio (on privately licensed frequency);
- » CB antenna;
- » Satellite telephone (encrypted, use to be limited to backup communication if CB radio unavailable); and
- » Cellular telephone with carrier service.

Real-time tracking and monitoring

One mechanism of tracking shipments is the use of a security escort. These escorts would maintain constant surveillance of the shipment. The responsibilities of security escorts are described in section 2.3.4.

Electronic or satellite equipment will also be used to track and monitor shipments. The NWMO will operate a central Transportation Communication & Control Centre (C&CC) located at the repository site that will provide a single point of contact for all agencies involved in transportation-related communications, and that will monitor and track used fuel shipments.

Each escort vehicle, tractor or railcar, and transport package will be equipped with a GPS unit for remote real-time tracking of their location. Additional best practices and available technologies will be reviewed for tracking and monitoring as they are proven reliable.

Scenarios 3 and 4

This responds to people's concerns about natural disasters (floods, fires, snow) and bad weather conditions impacting transportation. Constant communication with a central command centre during transportation will allow the NWMO to change course to avoid these types of events. If an event is detected along the transportation route in advance of a shipment, the shipment will not go out or an alternative route will be used.

2.3.3 Emergency management and security

Emergency management systems and security planning and protocols are the next layer of safety applied to the transportation program. These are systems put in place to prevent, mitigate and manage accidents and/or security threats. It is important to remember that transportation packages are designed to withstand extreme accident scenarios. That said, a road or rail accident can still have a significant impact on the transportation network. It is therefore important that plans are in place to manage these accidents should they occur.

Emergency management

In Canada, the emergency management community has adopted a standard approach for responding to incidents. Federal, provincial and local governments use a comprehensive approach to emergency management, which includes having in place measures for prevention, mitigation, preparedness, and response and restoration activities for all modes of transportation.

The NWMO will provide an emergency response plan to the Canadian regulatory agencies to demonstrate that appropriate emergency measures are in place. The purpose of the emergency response plan is to ensure co-ordination among the NWMO, provincial and local first responders, as well as federal agencies. It should be noted that first responders have general training on response protocol for dangerous goods, and any supplemental training or awareness programs would build on this knowledge base. Additionally, specialized teams with expertise and training in response and recovery would be dispatched by the NWMO in the event of an accident involving a transportation package.

Scenarios 5 and 6

The NWMO's transportation program is designed to prevent accidents; however, if an accident were to occur, the plan would need to address the scenarios identified, including recovery in remote locations and how the NWMO will work with other emergency response organizations, including volunteer responders.

The emergency response plan may include, but is not limited to the following:

- » Description of the emergency response organization and external agencies, as well as their roles, responsibilities, capabilities, and duties, and how they will work together;
- » Agreements on assistance with other facilities and/or other organizations;
- » Plans for mobilizing and deploying resources for response;
- » Description of roles and responsibilities (e.g., driver, escort, NWMO transportation command centre staff, first on the scene team, response team, recovery team, etc.);
- » Training and qualification requirements, as well as drills and joint exercises; and
- » Communication protocols, as well as procedures for alerting and notifying key organizations and personnel, as well as the public.

The NWMO will also need to consider either owning or contracting the following equipment to support emergency management preparedness.

Equipment	Purpose
Excavator	Excavation of trenches or access ways, ability to cut through heavy steel
Rotator tow truck	Ability to lift equipment, truck and trailers
Wheeled dozer	To push debris and away from the site
Wheel loader	To lift and load the debris into haulage vehicles
HiWay tractor	To haul equipment to/from incident locations
Heavy equipment float trailer	To carry equipment to/from incident locations
Mobile crane	Ability to lift transportation packages
Side-boom	Ability to lift equipment in tight area
Track loader/dozer	To push debris away from the site
Hi-rail vacuum truck	To vacuum away unwanted materials

As an additional support, Transport Canada operates Canadian Transport Emergency Centre (CANUTEC) – a national advisory service that assists emergency response personnel in handling dangerous goods emergencies on a 24-7 basis. The emergency centre is staffed by bilingual scientists specializing in chemistry or a related field and trained in emergency response.

The emergency response advisors are experienced in interpreting technical information from various scientific sources to provide pertinent and timely advice.

Security

Security planning must be done prior to transportation, and the NWMO must submit a transportation security plan as part of our application for a licence to transport used nuclear fuel. Like the transportation routes, the security plan is prescribed information and not available to the public. As part of this work, the NWMO must look at normal operations and worst-case scenarios to ensure plans are in place to respond to those scenarios. The security plan must include:

- » A threat assessment that looks at the nature, likelihood and consequences of acts or events that may place information or the used nuclear fuel at risk, along with corresponding mitigation measures, including emergency response;
- » Proposed security measures;
- » Communication arrangements;
- » Arrangements with response forces;
- » Planned and alternate routes;
- » Provisions for the support of response forces along the transport route;
- » Procedures for contacting, during transportation, the response force from any involved jurisdiction or agency;
- » Contingency arrangements to address such events as a mechanical breakdown of a transport or escort vehicle, or failure of a shipment to arrive at its destination at the expected time;
- » Procedures to be followed during an unscheduled stop or unscheduled delay during transport; and
- » Provisions for notifying any response force along the transport route in advance of the actual shipment.

In addition to the security plan, the shipments will be accompanied by one or more escorts. Their responsibilities would involve:

- » Conducting searches of persons, materials, vehicles;
- » Remaining in frequent contact with the shipper, receiver, local authorities, and response forces along the transport route;
- » Inspecting for security breaches and vulnerabilities, and ensuring the secure storage of any transport equipment; and
- » Responding to and assessing incidents and events.

Scenario 7

The transportation security plan addresses the concern about the package being a target for terrorist activities. It includes threat assessments that look specifically at these possibilities.

2.3.4 Management system

The final layer of safety applied to the transportation system is a management system that is focused on quality assurance, learning through experience, training, and auditing. This is one of the ways that the nuclear industry, as a whole, maintains its strong transportation track record. It is a combination of applying Canadian and international regulations and industry best practices.

The regulations described in section 2.2 outline requirements for training, monitoring and auditing. Specifically, the CNSC requires training of workers and emergency responders as part of the application for the licence to transport. The CNSC also performs compliance inspections and is responsible for investigating all incidents and emergency response situations that occur during transport. Transport Canada establishes requirements and undertakes compliance inspections for training and documentation. They also enforce requirements for emergency response planning.

In addition to these training, monitoring and auditing functions, the international nuclear community also has provisions for monitoring and auditing transportation activities and events. For example, the IAEA, which sets the standards for package design and testing, reviews and updates its requirements for transportation packages approximately every six years.

Personnel and training

The nuclear industry has very high standards with respect to driver/operator training. These standards are governed by regulations under the *Transportation of Dangerous Goods Act*, 1992, c.34. Training requirements set out in this act identify that drivers must be certified and have adequate training. Training must cover the following:

- » The type of material the driver/operator is carrying;
- » Safe handling practices, including the characteristics of the dangerous goods;
- » Proper use of equipment;
- » Reasonable emergency measures the person must take to reduce or eliminate any danger to the public;
- » The emergency response plan for that specific shipment; and
- » Documentation and reporting requirements.

Transport Canada ensures that all these training requirements are met prior to issuing a training certificate and will also do spot checks during transportation programs to ensure that training certificates are up-to-date.

3. The road ahead

As discussed, this document is the NWMO's preliminary plan for how we will approach transporting used nuclear fuel from interim storage facilities to the eventual repository site, beginning in the 2040s. Recognizing that this is approximately 20 years away, this work will continue to be expanded on and refined to incorporate emerging technologies and possible changes in infrastructure, as well as public priorities through our collaborative transportation planning process. The following paragraphs describe the work that the NWMO will carry out over the upcoming years as we work towards our ultimate goal of protecting people and the environment. Future iterations of this document will provide updates on this work as it progresses.

Routing

Once a site is selected, detailed routing analyses will be completed to establish primary and alternate routes. Route selection criteria will be established, prioritizing the use of high-quality infrastructure and using shortest route options while also considering potential hazards.

Since transportation is not expected to begin until the 2040s, we recognize that transport infrastructure and networks may evolve over time and while our work is ongoing, influencing final and alternate route selection.

Transportation safety

The NWMO is planning a multi-year work program on transportation safety of used nuclear fuel. Anticipated areas of work include:

- » Gathering information on federal, provincial and route-specific accident data to assess the type, severity and cause of accidents to better understand issues that lead to transport accidents;
- » Based on available accident data:
 - Identifying best available technologies that can be implemented to prevent accidents from occurring such as speed limiters, collision avoidance systems, duress buttons, etc;
 - Identifying best practices and operational programs that can be implemented to mitigate potential accidents (see *Operational best practices* on the next page);
- » Assessing doses to members for the public and workers (crew/escorts) under both routine and normal conditions of transport, as well as accident scenarios, to ensure that they are safe; and
- » Assessing risks associated with a range of transportation accident scenarios.

Emergency management

The NWMO plans to continue work in the area of emergency management and planning. A conceptual level operational plan will be developed in the future. At a minimum, this generic emergency management plan will:

1. Define accidents and hazards the emergency management program will address;
2. Establish a conceptual response plan and describe how a response will be executed; and
3. Ensure that people, equipment and infrastructure will be ready to execute the response plan and procedures.

A more comprehensive emergency management plan will be developed as details about mode, package and routes are finalized.

Security

The NWMO is initiating work in the area of transport security. Specifically, the NWMO is looking to develop a robust transportation security framework to ensure that used nuclear fuel can be transported in a secure manner.

This work will consider regulatory requirements, operational experience and best practices both nationally and internationally. It will also be the basis for the transportation security plan, as well as a threat risk assessment, which are required before any shipments of used fuel can occur.

After site selection and closer to the start of operations, a comprehensive transportation security plan that establishes detailed co-ordination with appropriate municipal, provincial and federal law enforcement agencies and threat risk assessment will be developed.

Operational best practices

The NWMO is committed to continued monitoring of international and Canadian best practices in the area of radioactive material transport. Review of the following is planned:

- » Frequency and level of examination of transportation package inspection and maintenance;
- » Frequency and level of examination of truck or train inspection and maintenance;
- » Training development standards for transport crew and personnel;
- » Frequency and scale of emergency response plan testing;
- » Indicators and metrics during monitoring and tracking of shipments (location, traffic, weather), as well as real-time analytics (speed, brake pressure) of conveyance during transport; and
- » Operational controls and limits, e.g., safety protocols implemented during changing transport conditions, route guidance and control, parking management and protocols in the event of traffic congestion, severe weather, and other external events (such as forest fires, snowstorms, flooding, tornados, etc.).

Transport infrastructure

Following site selection and finalization of decisions on transport modes and routes, it is anticipated that transportation infrastructure improvements or upgrades may be required. Collaboration with transportation system owners will be undertaken to address safety and service gaps along primary and alternative transportation routes.

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Appendix H – Transportation Planning Framework for the Transportation of Used Nuclear Fuel

Moving forward together

Planning framework for
the transportation of used
nuclear fuel

December 2021



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1. The task ahead

For more than 50 years, we have drawn power on a large scale from nuclear energy. One of the byproducts of this electricity production is used nuclear fuel, a solid material that is hazardous and needs to be contained and isolated from people and the environment, essentially indefinitely.

Used nuclear fuel is currently managed in licensed storage facilities, many of which are located at nuclear power plant sites. This storage is interim and requires active care to maintain. The concrete and steel containers that currently contain the used nuclear fuel need to be replaced every 50 to 100 years, and the buildings in which these sit need to be continuously monitored and maintained.

Canada has a plan that puts in place a long-term management approach that will safely and securely contain and isolate used nuclear fuel in a passive manner – a manner that does not require future generations to take care of a waste they did not produce or benefit from. Canadians and Indigenous peoples (First Nations, Métis and Inuit) have said it is unfair to put the responsibility for taking care of this waste on to future generations when we have the knowledge, capacity and resources to safely and securely put in place a long-term management plan today. Additionally, our dialogue with Indigenous peoples has told us that we can and should look to Indigenous Knowledge and the seven grandfather teachings as we consider how to plan for the future.

Transportation is an essential step in the implementation of Canada's plan. The used fuel must be transported from where it is currently stored today, on an interim basis, to a centralized location. While the transportation of used nuclear fuel occurs on a small scale in Canada today, the transportation of all Canada's used nuclear fuel will be a significant undertaking – one that we want Canadians and Indigenous peoples to provide input to and help us plan.

Many decisions about transportation will be technical in nature and must adhere to a strict set of regulatory requirements. That said, the Nuclear Waste Management Organization (NWMO) is committed to involving people in this process. In particular, Indigenous peoples, first responders and municipalities that have questions, concerns and an interest in helping to shape transportation plans. Indigenous voices have historically not been heard on these issues. We believe that, in particular, those voices can help guide the development of this plan, providing insights into the application of Indigenous Knowledge and how the NWMO could engage with rights holders whose traditional territory used fuel may pass through. We will also look to our Reconciliation Policy to help shape this work.

This document is based on discussions with Indigenous peoples, municipalities, first responders, citizens and civil society organizations. It describes a framework for transportation planning that is emerging, as well as a proposed implementation approach. It will be updated every three years to reflect what we are hearing from our ongoing dialogue.

Canada's plan

Canada's plan, known as Adaptive Phased Management (APM), moves towards a goal that Canadians themselves identified: safe, secure, long-term containment and isolation of used nuclear fuel produced in Canada, with flexibility for future generations to refine the approach, and adapt to experience and societal changes.

Canada's plan involves placing our country's used nuclear fuel in a deep geological repository in a suitable rock formation using a multiple-barrier system. A fundamental tenet of Canada's plan is incorporating learning, including Indigenous and Traditional Knowledge, at each step to guide a process of phased decision-making. APM is designed to be flexible and responsive to new learning, societal priorities and evolving public policy.

Developing the long-term management facility for Canada's used nuclear fuel is a national environmental infrastructure project. The facility will be sited in an area with informed and willing hosts. Canada's plan was developed through discussions with a broad cross-section of people nationwide.

Site selection

Since 2010, the NWMO has been working collaboratively with interested communities to identify a single site where Canada's used nuclear fuel can be contained and isolated over the long term.

Twenty-two communities initially came forward to learn about the project and explore the potential to host it in their area. A series of increasingly detailed studies to assess potential to meet the project's rigorous technical, safety and social requirements have informed a gradual narrowing down process.

Current work focuses on two remaining siting areas that have strong potential to meet the requirements of the project. We are advancing detailed technical and social studies, and continuing dialogue with First Nation, Métis and municipal communities in these areas to support learning about the project and a process of shared decision-making.

We expect to select a single, preferred site in 2023.

Partnership

We are implementing the site selection process using a partnership approach. Engagement, dialogue and collaboration help ensure that any community and area that is selected to host this facility is both informed about the project and willing to host it.

Ultimately, the preferred repository site will be one that can safely and securely contain and isolate used nuclear fuel for the time period required. Our approach to partnership is grounded in Reconciliation – where municipalities and Indigenous communities have mutual respect for each other. The project will only proceed in an area with informed and willing hosts, where the municipality, First Nation and Métis communities, and others in the area are working together to implement it.

Transportation

Transportation of used nuclear fuel is an important component of APM. Used nuclear fuel is currently safely stored in facilities licensed by the Canadian Nuclear Safety Commission (CNSC) at or near sites where it is produced. Placing all Canada's used nuclear fuel in a single location will require transportation from these interim storage facilities to the deep geological repository.

Transportation will involve placing these solid used fuel bundles in a transportation package that is specially designed to protect people and the environment during transportation, including in accident conditions. These transportation packages will be transported by road and/or rail, depending on the location chosen for the deep geological repository.

Transportation of radioactive material is a well-established practice with a strong track record of safety. Transportation of used nuclear fuel is subject to stringent regulation and oversight. The NWMO will need to demonstrate to regulatory authorities the safety and security of any transportation system before transportation to the repository can begin. We have also committed to demonstrating social safety to the public because the transportation of used fuel bundles will go through many traditional territories, municipalities and communities.

APM transportation is expected to begin in the 2040s and take about 50 years to complete.

A few facts at a glance

- Used nuclear fuel is a byproduct created when nuclear power plants generate electricity. It remains radioactive for a long period of time, and must be contained and isolated from people and the environment, essentially indefinitely. Used CANDU nuclear fuel (the fuel used by Canadian reactors) is not a liquid or a gas – it is a solid. It is not flammable, fissile or explosive.
- As of June 30, 2021, Canada had approximately 3.1 million used fuel bundles in temporary storage. If Canada's existing reactors operate to the end of their planned lives, including planned refurbishment, the inventory of used fuel that will need to be shipped to the repository could be about 5.5 million bundles.
- Canada's plan was developed for managing only Canada's used nuclear fuel. No used fuel from outside Canada will be placed in the APM repository.
- There is a great deal of experience in the safe movement of used nuclear fuel and other radioactive material both in Canada and around the world. In over 50 years, there have been more than 20,000 shipments worldwide of used nuclear fuel using road, rail and water transport without serious injuries, health impacts, fatalities or environmental consequences attributable to the radiological nature of the shipments.
- When the repository begins operation many years from now, used nuclear fuel will be delivered to the repository site at a rate that allows it to be placed in the repository as it is received.
- The transportation program may involve use of roadways, railways, or a combination depending on the site selected to host the repository.
- The transportation program is expected to extend over approximately 50 years or more, based on current anticipated volumes from nuclear facilities. If an all-road approach were taken, this might involve about 620 truck shipments each year, approximately one to two shipments per day. If an all-rail approach were taken, this might involve about 60 train shipments each year, approximately one shipment every six days.

2. A shared vision

Planning and implementing the transportation program is an important component of APM, one that requires a shared vision. During the past several years, the NWMO has been leading a dialogue with interested individuals, organizations, and municipal, First Nation and Métis communities to develop a framework to support this planning. A shared vision has emerged from these conversations.

The NWMO has been part of thousands of conversations as part of the process of learning about and reflecting on the transportation of used nuclear fuel and requirements of any socially acceptable APM transportation plan. People have often begun conversations by expressing fear, concern and opposition to even engaging in the discussion. We often heard, “No one asked my permission to create this waste in the first place,” “Dump it in your own backyard!” and “You are talking about a mobile Chernobyl.” As we acknowledge and begin to address these concerns, we see a shared vision forming that requires a deep respect for all people and the land we all share.

We have heard people reflect on our shared responsibility as a society for managing the used fuel we have created. When people begin to learn about our technical capacity to safely transport this material, and the fact that it exists today and has been around for about 70 years, often they move beyond their initial fear to then considering and addressing this challenge.

There are many aspects of a planning framework where, together, we appear to have strong agreement. There are other aspects on which we do not all agree, and these will need to be explored as transportation planning progresses. However, our many areas of agreement form a strong foundation to begin planning and continue those discussions.



3. The framework

The planning framework depicted below is built around objectives, principles and criteria shared by a broad cross-section of Canadians and Indigenous peoples through dialogues over the course of 2018-21. These areas of common ground are the starting point for the framework.

Underlying this discussion, we heard a strong commitment to the importance of successfully implementing Canada's plan, including the transportation program, and acknowledgment that hard work will be needed to engage broadly and find a way to work together. People shared their thoughts about the challenges they see ahead, which will require us to work together over the coming years to develop ways to address them. A strong framework of objectives, principles and priorities will help guide this collective work as we advance planning.



a. Basic requirements: What needs to be considered in transportation planning?

The plan is focused on several key areas that reflect the perspectives of Canadians and Indigenous peoples as shared through dialogue and form the foundation for the plan.

Safety is first and foremost on this list and must consider the public, workers and the environment.

Beyond ensuring safety, preventing, or if not possible minimizing, impact on the environment, including protecting water as the foundation for all life, is a requirement.

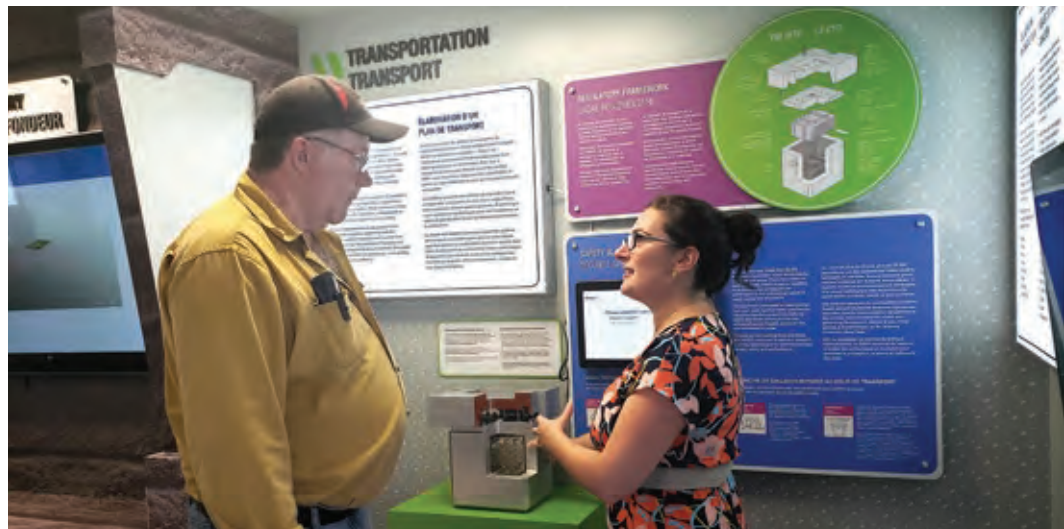
Planning for, and addressing, threats to security and potential emergency scenarios, and adopting best practices for training, monitoring, tracking, and auditing is a requirement.

Ensuring that the program is both adaptable and sustainable given the long duration of the transportation program is a requirement.

Communication is also a requirement as people have a basic 'right to know' about Canada's plan and the transportation program. Proactive communication is required to build awareness and confidence in the program. This communication will need to be balanced by an understanding that some details must be kept confidential for security reasons.

Engaging communities affected by the program is also a requirement, especially concerning the planning and construction of new infrastructure and facilities associated with the program.

In the spirit of Reconciliation given historical wrongs in Canada's history and a desire to build more positive relationships going forward, special consideration needs to be given to including and involving First Nation and Métis communities that may be affected by the program.



Safety is the primary consideration

Safety needs to be the first consideration. We need to consider the public, workers and the environment.

Protecting the environment

We need to ensure that the plan prevents, and where not possible, minimizes and mitigates impact on the land that is our shared responsibility. The protection of water is important as it is the life source upon which every person, plant and animal relies.

Emergency response planning

There needs to be advance planning and preparation for potential emergency scenarios, both through technical study and putting in place a program to support first responders along the route.

Drawing on international lessons learned

We need to ensure that Canada's transportation plan for moving used nuclear fuel is informed by the best available knowledge and expertise.

Monitoring, tracking and auditing

Keeping track of the used nuclear fuel at all times throughout the transportation program is essential. This includes keeping track of containers, evaluating and auditing procedures and processes, and holding people accountable.

Communication, education and engagement

People, particularly those living in communities along the route, have a 'right to know' about the project. It is important to proactively provide easily understandable information, and address questions and concerns in order to proceed.

Considering infrastructure

Collaboration with transportation system owners is anticipated to address safety and service gaps along primary and alternative transportation routes.

Respectful relationship with First Nation and Métis communities

Respecting Indigenous peoples' relationship to the land and working to acknowledging the knowledge that can be shared through respectful dialogue with First Nation and Métis communities.

Security

We need to plan for and address possible threats.

Ensuring that the plan is adaptive

Considering the transportation program will extend over several decades, the plan needs to be able to accommodate changes in science and technology.

Training

Because used nuclear fuel is very hazardous, the highest standards must be met in areas such as employee qualifications, security screening, training, and certification.

Ensuring program sustainability

Given the long-term nature of this project, a solid financial and political foundation will be important for the sustainability of the program required to complete it.

b. Objectives and principles

The objectives and guiding principles for planning are designed to reflect the perspectives of Canadians and Indigenous peoples that emerged through dialogue. These objectives and principles build on the basic requirements.

Planning objectives

Protect the public and workers: Eliminate or mitigate hazards associated with the transportation of used nuclear fuel. Safety and security form the umbrella under which all other objectives and principles must be considered. Safety includes protection of the public, workers and the environment from potential hazards associated with managing and transporting used nuclear fuel.

Security: Ensure the security of facilities, materials and infrastructure. Security is intimately related to safety but must be considered separately. The risk of malicious threat must be considered, factored into planning, and addressed in order to ensure public confidence. The plan must ensure the security of facilities, materials, infrastructure, workers, and the public, including consideration of cybersecurity, while transporting used nuclear fuel.

Protect the environment: Ensure that the environment is protected. We need to understand our potential impact on the environment and put in place plans to mitigate it. This includes risks to the environment through “spills,” greenhouse gas emissions (carbon footprint associated with transporting the fuel) and other impacts (e.g., from improvements to transportation infrastructure). Events such as forest fires, snowstorms and tornadoes that could impact transportation also need to be considered. Protecting water is very important.

Relationship with First Nation and Métis communities: Build respectful relationships with Indigenous peoples. Working positively and respectfully with First Nation and Métis communities, and understanding their unique perspectives, values and priorities is considered of utmost importance. The plan must also respect the constitutional rights of Indigenous peoples, reflect treaties, and consider that there may be unresolved claims between Indigenous peoples and the Government of Canada.

Project finances: Ensure economic sustainability of the project, without compromising safety, security and the environment. There must be financial surety in place in order to be confident that the full transportation program will be completed, and over time, safety will not be compromised because of lack of funds. This includes a secure source of funding, and confidence there is sufficient funding to avoid the need to increase electricity rates and/or taxes in the future to cover costs.

Guiding principles

Safety: Safety should be the overarching principle guiding all APM planning and activities. Safety, security, and protection of people and the environment are central and must not be compromised by other considerations.

Regulatory requirements: Meet or exceed regulatory requirements for the protection of health, safety and security of people and the environment. The plan must meet, and if possible exceed, all regulatory standards and requirements and respect Canada's international commitments on the peaceful use of nuclear energy.

Transparency and trust building: Information used to make decisions about transportation planning must be readily available to the public. The NWMO must be transparent in its approach to its work, including its interaction with the public (e.g., in communicating potential risks). Transparency is understood to be key to gaining public trust, and therefore, advancing the program. Information used to make decisions about transportation planning must be made public and readily available (e.g., transportation package certification, selection of transportation mode).

Balancing adaptability and continuity: The transportation plan needs to be flexible to continuously incorporate new learning, while maintaining continuity throughout changes in government. The planning framework must ensure that the transportation plan is flexible enough to continuously incorporate the latest and best science and technology, and provide continuity throughout the project; particularly with respect to project finances and changes in government. The program must be able to respond to changes in the regulatory framework, technology or infrastructure.

Evidence-informed decision-making: The plan must be informed by the best relevant available knowledge. This includes science, social science, local knowledge, Indigenous and Traditional Knowledge, and ethics. Knowledge holders in these areas need to be part of decision-making and involved in the process.

Incorporating Indigenous and Traditional Knowledge: Ensuring the insight from Indigenous science, Traditional Knowledge and ways of life is interwoven throughout is important for a strong plan. This includes knowledge about the land and ecology. It includes knowledge about developing and maintaining effective and meaningful relationships. Finally, it includes looking to the seven grandfather teachings for guidance as we plan for the future.

Responsible project management: The plan must be managed in a fiscally responsible way so that the cost of the project does not become a burden to current ratepayers or future generations. This will also provide confidence that future safety will not be compromised for cost considerations.

Informing and engaging: People, particularly those living in communities along the route, have a 'right to know' about the project and feel confident in its safety. It is important to proactively provide easily understandable information, and address questions and concerns, in order to proceed. Information needs to be provided at multiple levels of detail, from short descriptions that are easily understood by a lay audience to detailed technical reports for those who wish to review the findings in more depth.

c. Ensuring safety

The approach to safety is necessarily a holistic one that considers the public, workers and the environment (e.g., delicate ecosystems, animals, plants, water, and air). One Indigenous participant captured this sentiment in saying that he doesn't make a distinction between nature and people. So if one is hurt, all are hurt; we are all part of nature. This understanding of the need to 'look at the whole' was echoed in various ways by many people across the many discussions and appears to be a fundamental underpinning and point of agreement.

The holistic approach takes into account both radiation and non-radiation related impacts. For instance, measures need to be taken to protect people and the environment from the release of radioactive materials, and also from other impacts associated with the transportation program such as greenhouse gas emissions. The potential for injury from conventional traffic accidents, which may be influenced by the poor state of some roads, must also be taken into account. Similarly, the risk of public inconvenience must be considered, for instance the potential for used nuclear fuel transportation to impact the flow of traffic, to slow traffic or contribute to traffic congestion, detours, wear and tear of roadways, and road closures.

Science, including Indigenous science, and evidence-based decision-making in the development needs to play a prominent role in planning. Technical specialists have a role to play in helping to build awareness and understanding of the program and broad public confidence in safety and readiness to proceed.

Three key streams of work are important to establishing safety:

- » Ensuring a strong scientific and technical foundation for the plan to ensure best knowledge and expertise informs the plan;
- » Ensuring a comprehensive testing program; and
- » Ensuring a strong program of regulatory oversight and review, being able to meet or exceed regulatory requirements, and having a strong emergency response program in place.

This needs to include work to address the sensitivities and concerns of First Nation, Métis and municipal communities with respect to the science behind the plan. In the case of container testing, this needs to include consideration of the lived experience of people with direct knowledge and experience with the transportation routes.

Being assured there is stringent container testing will be particularly important. This includes an understanding of the testing already conducted to date, as well as using the Canadian used fuel transportation package in a series of new and contemporary testing. This needs to explicitly address transportation logistics during standard and extreme weather events (e.g., snowstorms, forest fires, tornadoes) and factor these into assessment and planning.

Ensure strong scientific and technical foundation for the plan

A strong scientific and technical program needs to address regulatory requirements and reflect best practices. The technical program needs to provide:

- A tested and certified transportation package;
- A plan to meet commercial vehicle and railroad safety and security requirements;
- A transportation security plan;
- An emergency response plan;
- A plan for regular reviews;
- A program for hiring high-quality and well-trained workers and vehicle operators;
- A plan for training and joint exercises with provincial and community emergency responders; and
- Procedures for safe and secure operations.

Program activities must include:

- Identifying and technically assessing road and rail modes of transport and mode combinations;
- Developing approaches to handling used nuclear fuel during transport, including logistics for transporting used nuclear fuel from interim storage facilities to the siting regions;
- Assessing risks associated with a range of transportation accident scenarios;
- Identifying and technically assessing transportation package options to ensure protection of the public and the environment during normal operations, as well as accident conditions;
- Studying risk and approaches to controlling exposure to the public and workers;
- Outlining an approach for emergency response and shipment security;
- Constructing and testing all equipment required for loading, transporting and unloading used nuclear fuel transportation packages, including truck trailers and/or railcars;
- Developing package designs for transportation packages, considering scenarios based on local knowledge and/or experience;
- Reviewing and reporting on experience and best practices with transportation of hazardous materials; internationally, to identify lessons that can be applied;
- Completing public and worker dose assessments associated with various package designs and scenarios for licensing review, as well as develop a program of ongoing monitoring and testing once transport of used nuclear fuel begins; and
- Securing and maintaining CNSC design certificates for road and/or rail transport packages.

Comprehensive testing program

Comprehensive testing of the container, and broadly sharing the results of this testing, is important for public confidence in safety. The testing program must address a range of scenarios.

Used nuclear fuel transportation packages must be designed and tested to ensure protection of the public during normal operations, as well as during accident conditions. Testing must be conducted to ensure the package can survive all plausible accident scenarios without releasing its contents. It builds confidence that these tests are conducted in sequence to simulate stresses that would cause the most damage to the package and total cumulative effects. As planned and as required by regulatory authorities, tests need to include the following:

- Free-drop test: The package is dropped from nine metres (30 feet) onto a flat, unyielding surface (such as a steel-reinforced concrete pad), striking the surface in the orientation that will result in the most damage to the package.
- Puncture test: After the drop test, the same package is subjected to a one-metre (40-inch) free drop onto a 15-centimetre (six-inch) diameter steel bar at least 20 centimetres (eight inches) long.
- Thermal test: The same package used in the drop and puncture tests is then subjected to a fully engulfing petroleum fire. The fire temperature must reach 800 degrees Celsius (1,475 degrees Fahrenheit) for 30 minutes.
- Immersion test: Using either computer analysis or physical testing methods, the package is subjected to external pressure that is the same as if it were immersed under 15 metres (50 feet) of water for at least eight hours to test for leakage. The package is also subjected to an enhanced water immersion test at 200 metres (650 feet) to test its ability to withstand extreme external pressures.

Beyond these tests, a broad range of accident scenarios must be considered, scenarios that mirror the lived experience of people who regularly travel these routes. These scenarios include:

- Train derailments in remote areas with limited access;
- Road or rail accidents resulting in the transportation container falling from a bridge over nine metres, similar to bridges in the area;
- Accidents resulting in the transportation container falling down a steep rock-face into a water source;
- Accidents where the entire vehicle rolls down a steep rock-face;
- Accidents involving fires burning at higher than 800 degrees Celsius or for a longer duration, for instance in a remote location in the midst of a forest fire;
- Road accidents involving a head-on collision with another truck carrying dangerous goods;
- Accidents resulting in the transportation package being under water for longer than eight hours, for instance in a remote location with retrieval challenges; and
- Train derailment with other dangerous goods in the vicinity, such as the Lac Mégantic and Mississauga train derailment disasters.

Meet or exceed regulatory requirements for safety and emergency response

Meeting, if not exceeding, stringent regulatory requirements is important for public confidence in safety. There is a responsibility to build broad awareness of these requirements, as well as shared work that demonstrates the APM transportation program's ability to meet or exceed them. This includes the three areas detailed below, as understood by the NWMO.

Safety: Packages used to transport used nuclear fuel from interim storage facilities to the repository need to be certified by the CNSC. Radiation levels from the package need to remain below regulatory limits at all times, including during transportation accidents. In order to confirm that the transportation package will do its job, packages must pass a series of performance tests specified in the regulations to demonstrate their ability to restrict loss of contents and to provide adequate shielding.

The safety of the transportation vehicle must also be demonstrated. Transport Canada, the entity that regulates the transport of dangerous goods, has a number of checks and balances to ensure that transporters adhere to a strict set of standards that a) are meant to prevent accidents (e.g., driver training requirements); and b) provide clear direction on how to manage accident scenarios (e.g., emergency planning requirements).

Security: Security provisions during transportation need to meet CNSC regulatory requirements, including the development and implementation of a transportation security plan. Components of a security plan are expected to include:

- A complete description of the material being transported;
- Threat assessment to identify any credible threats;
- Description of mode of transportation;
- Proposed security measures (e.g., escorts or continuous tracking);
- Communication arrangements between the NWMO and the carrier along the route;
- Response arrangements between the NWMO and any policy/response forces;
- Primary and alternatives routes; and
- Provisions for stopover during transport.

Emergency response: Emergency response planning requirements will need to be met, ensuring workers and first responders are trained before shipments can begin. The NWMO will need to work with local response agencies to co-ordinate planning and preparedness activities before transportation can begin.

Although existing supports are available (e.g., Canadian Transport Emergency Centre) and training covers incidents involving dangerous goods, including radioactive material, access to training can be budget-dependent. The NWMO needs to work with first responders along transportation routes to understand specific information and training requirements, and ensure that all parties have appropriate information, resources, training, and a clear understanding of roles and responsibilities in the event of an accident.

d. Protecting the environment

Ensuring that the plan protects the environment and mitigates any impact where they cannot be eliminated is important. This includes consideration of both radiation-related and more conventional impacts on the environment.

The release of radioactive material into the environment needs to be eliminated, and where not possible, mitigated and minimized. People are concerned about potential for an accident or act of terror to cause used nuclear fuel to enter the soil, water and/or contaminate the air. The plan should include measures to prevent environmental damage, as well as ensure that specialized resources and response mechanisms are in place to mitigate and repair damage to the environment should an incident occur.

The plan needs to also take into account and minimize more conventional impacts over the course of day-to-day transportation operations. Specifically, greenhouse gas emissions from trucks or trains and disturbance to sensitive areas from road or rail work that may be needed to support the transportation program.

The transportation plan must not only ensure safety by meeting or exceeding regulatory requirements, but it should also go beyond this through specifically minimizing impact of the transportation program on the environment. Seeking opportunities to incorporate green technology in day-to-day operations of the transportation program was an example mentioned by many.

The protection of water is important. Expressed in different ways by different people, the importance of water was pinnacle, as it is the life source or life blood of the earth upon which every person, plant and animal relies. People talked about the importance of larger water bodies and also streams and rivers as connectors.



Protecting the environment

We heard that the program must include:

Measures to prevent environmental damage from radiation contamination:

- These measures need to prevent or minimize used nuclear fuel escaping from the cask into the environment, including acts of terrorism and sabotage.

Measures to prevent environmental damage from non-radiological impacts:

- Greenhouse gas emissions from the vehicles used;
- Impacts that improvements to infrastructure (e.g., widening roads, building segment of dedicated rail lines, reinforcing bridges) may have on the local environment, especially around fragile habitats; and
- Impacts of conventional accidents on the environment (e.g., diesel spills).

Resources and response mechanisms to mitigate and repair damage should an incident occur:

- Emergency response plans are in place; and
- Local first responders are trained and equipped for accident scenarios.

Use of green technologies:

- Incorporating green technology as it becomes available.

We heard the following considerations are also important to take into account:

- Impact of environmental conditions along a route on safety, such as forest fires, snowstorms and tornadoes;
- Use of off-sets to make up for negative impacts on the environment (e.g., planting trees, rehabilitating habitat);
- Implementing a system of environmental monitoring of radiation and of impacts of transportation on the environment (e.g., wildlife, sensitive habitats); and
- Impacts related to the manufacturing of transportation equipment.

e. Relationship with the land

While environmental protection is key to the work that the NWMO is doing, there is much that we can learn from the land and people's relationship with the land. Through the NWMO's Reconciliation work and the conversations we have had with Canadians and Indigenous peoples, we recognize that we must listen to the important teachings given to us. In doing this, we can build trust and find ways to work together.

We are the land. The land is us. From discussions with First Nations, Métis and municipal leaders, including camp owners, hunters, harvesters, and fishers, we heard that transportation corridors are important thoroughfares used by both people and animals. Transportation corridors also pass over and connect many water bodies. We were also told that this connection to the land extends over generations, past, present and future. People are adamant that these water bodies and the land around them be protected from any harm to protect not only this generation, but also past and future generations. It will be important for the NWMO to consider these connections and look to people and ceremony for guidance on this program.

Fundamentally, it will be important for transportation planning to integrate the principles described in the NWMO's Indigenous Knowledge Policy. For example:

- » The NWMO will continue to honour spirit and ceremony as a core value within Indigenous Knowledge;
- » The NWMO acknowledges that Indigenous peoples are holders of Indigenous Knowledge, and recognizes that Indigenous Knowledge is essential and integral to decision-making processes; and
- » The NWMO understands that Indigenous Knowledge, together with western science, is part of good decision-making when built on a foundation of trust and sharing of information in a respectful manner.

Respecting the land

Our conversations with people have helped us to begin to outline what respect for the land could look like:

- Water connects all of us and the past and future generations. Water must be protected, respected and looked-to to avoid mistakes of the past (e.g., contamination of water supply from industrial activities);
- Developing a culture-centred approach to engagement will allow the NWMO to seek insight from rights holders, keepers and guardians to understand the stories of the land and how to best respect and protect it;
- The NWMO should look to ceremony to incorporate the teachings of past, present and future generations into our transportation planning;
- Consider the seven grandfather teachings as we plan for transportation together to answer the question, "How does this initiative support Mino-Bimaadiziwin ('the good life' in Ojibway)?", which was asked of the NWMO at one of our engagement sessions.

f. Being inclusive

It is important to be inclusive when designing and implementing the plan. This is important to ensuring good decisions are made. We heard this is needed to ensure the project proceeds, and that people have an opportunity to learn about transporting this material about which there are natural fears and concerns.

There is an important role for government, an important role for experts, and an important role for critics to ensure the best knowledge and expertise are applied and the plan is safe. However, safety is not in itself sufficient. People said Canadians and Indigenous peoples need to be aware and informed, and prepared to see the program implemented. They need to learn about used nuclear fuel and the ability to transport it safely. They need to become informed, be able to ask questions and have their questions addressed. Many people should be involved in this conversation, including Indigenous peoples, communities along transportation routes, communities that currently host nuclear facilities, first responders, government officials, scientists, and technical experts.

The rights of Indigenous peoples need to be respected. Beyond that, there is a special duty owed by Canadians, given past history and historical wrongs to Indigenous peoples, and this means they need a special role in planning for this type of program. This will need to be worked out over time with the First Nation and Métis communities involved. Indigenous dialogue participants talked about formal rights and Crown duty to consult and consent. We also heard from Indigenous participants about the need to focus on a culture-centred approach to engagement that focuses on rights holders, keepers and guardians in our implementation process. Through this process, there is the potential for the program to develop new ways and new relationships built on mutual respect, and seeking opportunities for collaboration, shared planning and co-creation. We have also heard that now that Bill C15 has passed, the NWMO must consider how the United Nations Declaration on the Rights of Indigenous Peoples will apply to our work.

Raising awareness, building understanding and addressing questions and concerns that people will inevitably raise appeared to be considered essential by most who engaged in the dialogue.

Building respectful relationships with communities, both municipal and Indigenous, and informing and engaging people are among the key objectives identified for the plan. Being inclusive in developing and implementing the transportation plan is important, and there was much discussion about how best to achieve this. It is important that through the conversation, people grappled with what can be practically achieved, and what is workable and justified given the need to advance Canada's plan.

After much consideration and discussion among individuals and groups in a variety of engagement and dialogue settings over the past several years, a set of principles emerged to guide our path forward. We accept that the way forward will be challenging, but with patience and time, we can and will move forward together.

Inclusivity principles and activities

Over the course of discussions, people laid out a set of principles to guide first steps:

- **Awareness and understanding:** Canadians should have some measure of awareness and understanding about the transportation plan. Building awareness and informing people is a primary goal of the plan, and conversely, people have a responsibility to participate in this learning;
- **Focus on potentially affected communities:** People who are more directly affected by the transportation program should have greater opportunity to understand the plan and to be heard. Informing people and communities along the route, including nuclear host communities, should be a primary focus;
- **Special role for leaders and first responders:** Relevant government officials, municipal leaders, first responders, and scientific and technical experts should be involved. This will help to ensure good decisions are made;
- **Right to be informed:** People have a right to be informed about the plan. Good information and a desire to be informed are important for good decision-making; and
- **Special role for Indigenous communities:** Indigenous communities need to play a role in the development of the plan. They are rights holders, keepers and guardians of the land. Given the history of continuing and past wrongs as a country, it is imperative that positive and respectful relationships be built to advance the project.

People have also outlined some key activities as a starting point

Informing people: Engaging with communities along the routes is a high priority. The objective of this engagement should be to inform residents by providing information, answering questions and addressing concerns. 'People have a right to know.' This is seen as an important NWMO responsibility.

Assuaging fear: The NWMO needs to proactively alleviate fear about the transportation of used nuclear fuel before this fear becomes entrenched. We heard that over time, there is an expectation that community engagement should be able to reassure most community residents, and the broader public, about the project and the soundness of the transportation plan. It is a responsibility of the NWMO to inform people to move them out of a state of fear.

Building relationships: Building relationships, and establishing mutual trust and respect, are important. Building relationships with First Nation and Métis communities and organizations is important to ensure Indigenous values and priorities, questions and concerns, and insight from Indigenous and Traditional Knowledge inform the plan.

g. Selecting modes and routes

Any transportation plan for used nuclear fuel will need to provide a framework for making decisions about the method we will use (modes) and the transportation pathway we will use (routes). We may need to consider using a combination of modes, such as road and rail, depending on the location chosen for a repository. While we have not yet identified a preferred site, dialogue to date has identified factors that the public expects will be considered when we are ready for detailed decision-making.

In selecting modes and routes, first and foremost, safety and security must be the primary consideration. The pros and cons of various modes and routes must be thoroughly analyzed, and the best possible decision be made based on science, with a primary focus on safety and security. Considerations reflecting best practice and experience in Canada and internationally must be used. Local knowledge and lived experience related to specific roads and routes of people living in the area and travelling those routes must also be considered.

Many factors will need to be considered, and we heard we should look to transportation specialists to advise on how best to achieve or balance individual objectives when they may conflict.

Considerations for the selection of modes and routes

People expect best practice and experience to be taken into account in the selection of modes and routes in order to ensure safety and security. In exploring choices between modes and between routes, it will be important for them to see that factors such as the following are being considered, some of which mirror the lived experience of people who regularly travel routes in the area:

- Application of Indigenous science and local knowledge;
- Risk of accident (e.g., based on historical accident and operational data);
- Risk of security breach (e.g., relative ease of access);
- Adequacy of transportation infrastructure (e.g., quality of roads and tracks) with some indicating that much of their transportation infrastructure needs maintenance and modernization;
- Potential environmental impacts (e.g., on wildlife and surrounding terrain);
- Weather and the ability to adapt to seasonal changes (e.g., snow, ice, rain, and floods);
- Further understanding of Indigenous and local knowledge and application to transportation program (e.g., along potential transportation corridors);
- Ease of containment and access by first responders in the event of an incident;
- Analysis of the relative merits of opting for bigger loads and fewer trips versus smaller loads and more numerous trips;
- The frequency and nature of handling and transfers (particularly for worker exposure); and
- Adaptability of modes to future innovations in transportation (e.g., autonomous automobiles).

There will need to be some balancing or trade-offs between objectives. In doing so, there will need to be no compromise in safety. Transportation routes would and should be selected by experts based on a consideration of trade-offs, and pros and cons, including:

- Proximity to population centres and schools;
- Proximity to sensitive environmental areas;
- Proximity to water bodies;
- Response time for first responders/emergency response;
- Potential need to improve existing or build new infrastructure (e.g., extension of rail track);
- Conditions of the route during winter and inclement weather (e.g., days of rain and snowfall);
- Potential for traffic congestion and potential impact on commuters;
- Assessment of political and social acceptance;
- Trade-off between a longer route that goes through less densely populated areas versus a shorter route that goes through more densely populated areas; and
- The need to vary routes for security reasons.

h. The framework

A framework of public expectations, principles and priorities for the APM used fuel transportation plan is emerging from these discussions and is outlined below at a high level.

a. Basic requirements

- » Safety as the primary consideration;
- » Protecting the environment;
- » Security;
- » Emergency response planning;
- » Drawing on international lessons;
- » Ensuring that the plan is adaptive;
- » Training;
- » Monitoring, tracking and auditing;
- » Communication, education and engagement;
- » Building respectful relations with First Nation and Métis communities; and
- » Ensuring program sustainability.

b. Objectives and principles

- » Ensuring transparency;
- » Balancing adaptability and continuity;
- » A focus on evidence – informed decision-making;
- » Incorporating Indigenous and Traditional Knowledge;
- » Ensuring responsible project management;
- » A focus on informing and engaging; and
- » Attention to project finances.



4. Proposed approach to implementing the framework

We understand we need to take an approach that embeds the framework in decision-making throughout planning and implementation of the transportation program. The approach needs to be flexible and adaptive, and it needs to continue to involve people at key milestones along the way.



In this section, we propose key elements of a potential transportation plan, or management system, for discussion. It includes:

- » A plan for working together through engagement, collaboration and shared decision-making;
- » A readiness checklist, to be used by the NWMO and the public together, to regularly assess preparations to initiate the transportation program; and
- » A road map of key milestones and steps, including collaboration and shared decision-making, putting in place a strong scientific and technical foundation for the program, and meeting or exceeding regulatory requirements.

a. Collaboration and shared decision-making

We understand from what we heard that there is a need to involve people in decision-making all along the way, to ensure the program continues to reflect the principles and objectives important to the public. Here, we outline milestones for continuing to shape and advance the plan together.

Key milestones

1. Refine the draft framework and milestones (2020-21): Dialogue and engagement to review and refine the draft framework and reflect on the proposed management system.

2. Review an initial conceptual plan (2022-23): Dialogue and engagement to review an early sample transportation plan. This plan would be general in nature, as the repository site will not yet have been selected, but could be used to further explore expectations.

3. Review and refine site-specific transportation plan (2023 until initiation of transportation): Dialogue and engagement to review an early sample site-specific transportation plan. This plan would need to continue to be refined over the years leading up to the initiation of the transportation program, but could be a basis for further exploring expectations. This might involve:

- The NWMO working with people and organizations in the initial development of the plan, such as transportation specialists (e.g., Canadian and international scientists and engineers), federal and provincial government ministries and agencies (e.g., CNSC, Transport Canada, Public Safety Canada, and provincial ministries of transportation), and Canada's nuclear power generators.
- Including First Nation and Métis communities along potential routes, as well as Indigenous organizations, in planning and helping the NWMO understand how to consider traditional knowledge and culture-centred engagement in transportation planning.
- Addressing the questions and concerns of interested communities, individuals and groups as part of the transportation planning process, including first responders along potential routes, first responder associations/organizations, municipalities and municipal associations as a group with a shared interest, and other interested individuals and groups. Communities that currently host interim storage facilities will also need to be involved in planning how used fuel is moved through their community.

4. Build awareness and communicate about plans as they are refined (2023 until initiation of transportation): Dialogue and engagement to build awareness and understanding of the APM Project and transportation plan, and confidence in safety. We heard this is a critical component of any plan, and it will take time and effort to accomplish this. This may include activities such as face-to-face discussion and facilitating a dedicated virtual space for learning about the plan, asking questions, hearing from transportation specialists, and addressing frequently asked questions and concerns on an ongoing basis.

5. Monitoring and adapting (2023 onwards): Ongoing review of evolving best practices, new and emerging technologies and standards, and reflection on the need to refine and adapt the program. Monitoring will include ongoing review of experience in implementing the transportation program once it begins, including impacts and mitigations, to support reflection and adaption of the program during implementation.

We understand from what we heard that evidence-based decision-making is an important part of this process. We understand we need to continue to learn and build on best practices and evolving international and Canadian expertise, science and technical developments as we implement the program. We understand that transparency, auditing and reporting are key.

Here, we outline components of a potential program for reporting and continuous improvement to working together to shape and advance the plan.

Ongoing reporting and continuous improvement

We heard that ongoing reporting and continuous learning is important for the program to be able to adapt over time as needed. Ongoing reporting and continuous learning might include the following:

- 1. Monitoring and reporting on evolving best practice:** Beginning in 2023 and on a triennial basis, the NWMO publishes a report with updates on best practice, new and emerging technologies and evolving state of the art, evolving standards, and how it is adapting the program in the spirit of continuous improvement.
- 2. Monitoring and reporting on ongoing impacts and mitigations:** Once used fuel transportation begins, the NWMO monitors and regularly reports on public and environmental impacts, reportable events, and action taken in a manner that is understandable and accessible to the public. People have specifically identified that they are interested in being informed about the number of shipments and incidents in as real-time as possible.
- 3. Monitoring and reporting on project finances:** Beginning in 2023 and on a triennial basis, the NWMO publishes a report of the status of finances for the transportation program, including the project's cost and sources of funding.
- 4. Regular reporting on outcomes of engagement programs:** The NWMO currently publishes an annual *What we heard* report. The NWMO will continue to publish this document, which will describe engagement activities, questions raised, responses to those questions, and updates on the implementation of this framework.



b. Putting in place a readiness checklist

We understand there are a broad range of factors that need to be addressed before the NWMO and the public together will be ready to begin transporting used nuclear fuel as part of APM. Here, we outline our understanding of the factors and outcomes needed, in the form of a readiness checklist.

Using this checklist, we would regularly track and report on our progress in putting these necessary conditions in place. In this way, we would collectively gauge program readiness to begin with transport of the first used fuel bundle from interim storage facilities to the deep geological repository. Some of these activities will require involvement of specific parties (e.g., government, first responders). As we plan for transportation together over the next 20 years, we will further define roles and responsibilities associated with this checklist.

Readiness checklist

- ☐ A site-specific transportation plan;
- ☐ A broad-based awareness and education program for the general public and communities along the transportation route to meet the needs of different population segments (e.g., youth, elders);
- ☐ An ongoing engagement and dialogue with First Nation and Métis communities along the transportation route;
- ☐ Questions received about transportation are acknowledged, addressed and shared broadly;
- ☐ Awareness and training program for first responders along the transportation route;
- ☐ A tested and certified transportation package;
- ☐ Accident scenarios specific to transportation routes, including those that align with the lived experience of people in the area, have been covered by transportation package testing, and safety has been demonstrated;
- ☐ A transportation security plan that takes into account threats of sabotage and terrorism;
- ☐ An emergency response plan that explicitly describes resources available along the route, and roles and responsibilities, in the event of an accident;
- ☐ An environmental management or protection plan that takes into account the carbon footprint of the transportation program, and environmental response and remediation in the event of an accident;
- ☐ A confirmed plan to meet commercial vehicle and railroad safety and security requirements;
- ☐ A program for hiring high-quality and well-trained workers and vehicle operators;
- ☐ Procedures for safe and secure operations;
- ☐ A plan for regular reviews of all required plans, certifications and procedures;
- ☐ A 'safety audit' program involving ongoing physical assessment of the roads, bridges, etc. of the route, to identify structural weakness; required repairs to the infrastructure of the selected route – any required improvements or repairs would need to be done in collaboration with the infrastructure owners; and
- ☐ A program of reporting with updates on best practice, technologies and evolving state of the art, and ongoing activities to adapt the program in the spirit of continuous improvement.

c. Key milestones and steps

We understand from public discussion that we need to advance the plan through a sequence of steps, which include engagement, collaboration and shared decision-making; putting in place a strong scientific and technical foundation for the program; and meeting or exceeding regulatory requirements. This forms a basic road map to guide our working together with the public. It is important to note that all this work is in preparation for a transportation program. We will continue to talk with Canadians and Indigenous peoples about what shared planning and responsibility looks like after transportation begins in the 2040s.



2023 onwards

Ongoing review and public reporting

Beginning in 2023 and on a triennial basis, the NWMO publishes a report with updates on best practice, technologies, and ongoing adaptation and continuous improvement.

Once transportation begins, the NWMO monitors and regularly reports on public and environmental impacts, reportable events, and action taken in a manner that is understandable and accessible by the public. Ongoing public review is sought, as well as reflected on the shape and form of any refinement or adaptation to the program.

2038 onwards

Initiate capacity-building programs for first responders

Capacity building will provide support to first responders, as needed, along the route in preparation for the initiation of the transportation program and its ongoing implementation. This includes addressing skills development, equipment and service needs, which will be done prior to 2038 as part of Step 3.

• 2040

2024-40

Regulatory review

More detailed plans are developed and published to support transportation-specific regulatory oversight prior to any used fuel being transported.

The NWMO provides an emergency response plan to the CNSC, Transport Canada and the provinces, ensuring that information is available to relevant public emergency response agencies. The NWMO develops the transportation security plan.

~2040 onwards

Begin transporting used nuclear fuel to a deep geological repository

Beginning in about 2040 or so, the transportation program for APM is expected to continue for approximately 40 to 50 years, based on the current and anticipated volume of used fuel.

5. Regulatory decision-making

Canada has in place a stringent framework of regulation and oversight to review and approve transport of used nuclear fuel. Transportation of used nuclear fuel is regulated by the CNSC and Transport Canada. Used nuclear fuel shipments conducted as part of the APM transportation program will need to meet these requirements to ensure they are safe and secure. APM transportation operations will also need to meet federal, provincial and local safety legal requirements, and will be inspected to ensure compliance.

Consistent with this framework of regulation and oversight, we understand that approvals for APM used nuclear fuel transportation will be given if requirements are met. Requirements focus on the strength of the transportation package and include the following:

1. **Transportation package:** Used nuclear fuel transportation packages are designed and tested to ensure protection of the public during normal operations, as well as during accident conditions. The CNSC, using internationally tested standards, has the responsibility for evaluating the transportation package and certifying its design, the registration of the use of individual packages, and monitoring the package maintenance process.

Prior to transporting used fuel in Canada, the CNSC's comprehensive regulatory framework requires a certificate for the transport package and a licence to transport. The CNSC evaluates applications to ensure that safety and security measures are technically and scientifically sound, that all requirements are met, and that the appropriate safety and security provisions are in place to protect people and the environment. Packages used to transport used nuclear fuel from interim storage facilities to the repository must be certified by the CNSC.

2. **Radiological safety:** Packages used to transport used nuclear fuel must meet radiation level requirements prescribed by the CNSC's *Packaging and Transport of Nuclear Substances Regulations*, 2015. Regulatory requirements for the package ensure the public and workers are safe. The package is designed and tested to ensure that in the event of an accident, the radiological release will not exceed the regulatory limits. The CNSC's *Radiation Protection Regulations* have set an annual radiation dose limit for members of the public to limit exposure from nuclear-related activities.
3. **Emergency response and training:** Transport Canada's *Transportation of Dangerous Goods Regulations* establish requirements for worker and driver training, emergency planning, safety marks, and documentation. Transportation planning needs to address these aspects, and ensure that all equipment, packages, and activities for road and rail shipments meet regulatory requirements. The NWMO will need to demonstrate that all activities will be conducted by trained personnel, including emergency responders. The NWMO will also need to develop an emergency response plan, and ensure workers and emergency responders are trained before shipments can begin.
4. **Security:** Security provisions during transportation need to ensure CNSC regulatory requirements are met. Security measures are aimed at preventing diversion or sabotage of the transportation package, and include a combination of engineered, physical and monitoring measures to protect the cargo, and provide for detection, alarm, recording, and communication, in the event of an occurrence.

For more information on transportation regulation and oversight, see the NWMO's brochure *Safe and Secure Transportation of Canada's Used Nuclear Fuel*.

6. Next steps

Canada's plan for the long-term management of used nuclear fuel, known as APM, emerged from a dialogue with the public. The starting point for this plan is that this generation is taking responsibility for the management of the used nuclear fuel it has created and is not leaving it as a burden to future generations. Canada's plan requires us all to work together to implement it. Together, we can ensure APM transportation is implemented safely, and in a manner consistent with our collective values, priorities, and perspectives.

In this document, we have reported on what we are hearing about the broad framework within which APM transportation should be planned. Building on what we heard, we also describe a flexible and adaptive approach to implementing the transportation program, which continues to involve people at key milestones along the way, responsive to what people said is most important.

This framework document will be the foundation for transportation planning going forward and will be updated on a regular basis to acknowledge the evolving nature of this planning process.

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Appendix I – Worker Dose Assessment

Generic Transportation Worker Dose Assessment

NWMO TR-2014-17

December 2014

U. Stahmer

Nuclear Waste Management Organization

nwmo

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MANAGEMENT
ORGANIZATION

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Generic Transportation Worker Dose Assessment

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ABSTRACT

Title: Generic Transportation Worker Dose Assessment
Report No.: NWMO TR-2014-17
Author(s): U. Stahmer
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Abstract

In 2012, NWMO prepared a generic dose assessment which estimated radiological dose to members of the public due to the used fuel transportation program. The assessment looked at used fuel transport by the two land modes of transport, road and rail. Building on this work, this assessment looks at occupational dose due to used fuel transport.

This work provides a generic assessment of the potential occupational dose to transportation workers due to used fuel transport in Canada. As the location of the APM repository site is currently unknown, program specific calculations and risk assessments are premature. The intent of this assessment is to provide a starting point to address concerns about the safety of the transportation system in a transparent manner.

Transportation activities assessed in this report focus on activities workers are engaged in from the time a used nuclear fuel shipment departs from the reactor sites where the fuel is currently stored to its arrival at the repository site. Occupational doses were assessed to range between approximately 0.012 to 0.35 mSv per year with members of the transport crew receiving the highest dose. Since calculated doses remain below the regulatory dose limit of 1 mSv per year for a member of the public, this assessment concludes that transportation workers would not need to be designated as Nuclear Energy Workers. Findings for different transportation worker categories are tabulated in Figure S-1.

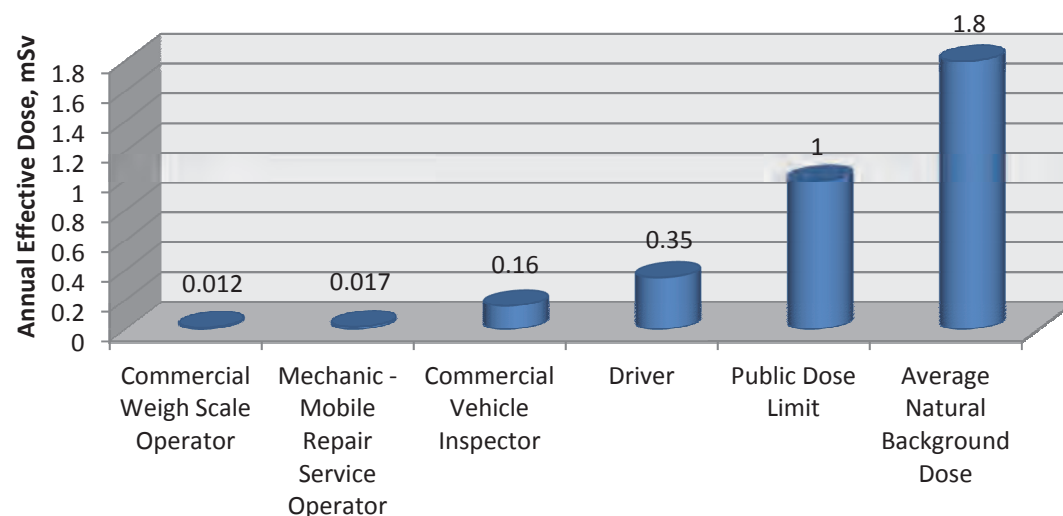


Figure S-1: Comparison of Worker Doses

ACRONYMS AND DEFINITIONS

ALARA	As Low As Reasonably Achievable. An optimization tool in radiation protection used to keep individual, workplace and public dose limits as low as reasonably achievable, social and economic factors being taken into account. ALARA is not a dose limit; it is a practice that aims to keep dose levels as far as possible below regulatory limits.
APM	Adaptive Phased Management. Canada's plan for long-term management of used nuclear fuel.
Burnup	A measure of how much energy has been extracted from a fuel bundle.
CANDU	CANada Deuterium Uranium. Canadian-invented, pressurized heavy water reactor. The acronym refers to its deuterium-oxide (heavy water) moderator and its use of natural uranium fuel.
CNSC	Canadian Nuclear Safety Commission. Canada's nuclear regulatory agency.
Conveyance	Any vehicle such as a truck, train or ship used to transport radioactive material.
CVSA	Commercial Vehicle Safety Alliance. An international not-for-profit organization comprised of local, state, provincial, territorial and federal motor carrier safety officials and industry representatives from the United States, Canada, and Mexico.
DGR	Deep Geological Repository as it applies to used fuel.
Effective Dose	The sum of the products, in sieverts, obtained by multiplying the equivalent dose of radiation received by and committed to each organ or tissue, as set out in CNSC's Radiation Protection Regulations.
Equivalent Dose	The product, in sieverts, obtained by multiplying the absorbed dose of radiation type, as set out in CNSC's Radiation Protection Regulations.
IAEA	International Atomic Energy Agency. United Nations nuclear regulatory authority.
ICRP	International Commission on Radiological Protection. An advisory body providing recommendations and guidance on radiation protection.
MCNP	Monte Carlo N-Particle Transport Code. The software code used to calculate dose rates emitted by the UFTP. See Section 3.2 and Appendix A.
NEW	Nuclear Energy Worker. A person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public.
Sv	Sievert. A sievert is the International System of Units (SI) used to measure radiation dose. The unit as used in this assessment is the millisievert (mSv), or one thousandth ($1/1000$) of a sievert (Sv).

Type B(U)	The type of package required for the transport of highly radioactive material including used nuclear fuel. The concept of a Type B(U) package is that it is capable of withstanding most of the severe accident conditions in transport without loss of containment or increase in external radiation level to an extent which would endanger the general public or those involved in rescue or cleanup operations.
UFTP	Used Fuel Transportation Package. The transportation package used to assess the radiation dose reported in this study. The UFTP is currently certified by the CNSC as a Type B(U) package.

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1. INTRODUCTION

Used nuclear fuel discharged from Canadian nuclear power reactors is currently stored at licensed interim storage facilities located at the reactor sites where it is produced. Adaptive Phased Management (APM), Canada's plan for long-term management of used nuclear fuel has as its endpoint safe and secure isolation of used nuclear fuel in a deep geological repository (DGR). Implementation of APM requires the transport of the used nuclear fuel from the interim storage locations to the repository site.

In 2012, NWMO prepared a generic dose assessment (Batters et al., 2012) which estimated radiological dose to members of the public due to the used fuel transportation program. The assessment looked at used fuel transport by the two land modes of transport: road and rail. Building on the work done in 2012, this assessment looks at occupational dose due to used fuel transport.

1.1 Assessment Purpose

The purpose of this work is to provide a generic assessment of the potential occupational dose to transportation workers involved in used fuel transport in Canada. As the location of the APM repository site is unknown at this time, program specific calculations and risk assessments are premature. The intent of this assessment is to provide factual data related to the safety of the transportation system in a transparent manner. This information will provide a basis for decision making, program planning and provide input for design optimization of the components of the transportation system.

1.2 Assessment Scope

This assessment estimates potential individual effective dose (hereafter referred to as 'dose') received by transportation workers resulting from the transportation of used nuclear fuel by road.

Road transportation was determined to be the bounding transport mode for calculating occupational dose to workers. This is due to the fact that workers in the road transport realm are, on average, in closer proximity to the UFTP for longer periods of time than during rail transport. Each transportation shipment is considered to start with the loaded package on the trailer ready to be picked up for transport. The shipment is considered to end when the trailer arrives at the APM repository site receiving bay and is disconnected from the tractor.

Activities including package loading, preparation for shipment, and securing onto the transport trailer which are conducted by workers at a licensed facility are outside of the scope of this assessment.

Occupational dose estimates are limited to normal conditions of transport. Doses due to accident conditions of transport are not addressed in this study. Public doses resulting from potential transport accidents bounded by the conditions defined in the Canadian and International Transport Regulations are assessed in Batters et al. (2012).

Worker doses are calculated for a number of transportation related activities. The calculated doses are compared to the regulatory dose limits defined in the Canadian Nuclear Safety Commission's (CNSC) Radiation Protection Regulations (CNSC, 2000b). Doses are initially compared to the limit for a member of the public to determine whether workers need to be designated as Nuclear Energy Workers (NEWs). If there are instances where dose results exceed the public dose limit, calculated doses are compared against regulatory dose limits for a NEW.

1.3 Assessment Basis

This analysis is based upon the following assumptions:

- a) Use of the reference transportation package, the Used Fuel Transportation Package (UFTP). The UFTP was first certified in the 1980's. In 2013, the UFTP was recertified to demonstrate it meets current regulatory requirements.
- b) The UFTP is loaded with 192 CANDU style 37 element used fuel bundles aged, on average, 30 years out-of-reactor. Fuel burnup is discussed under (h) below.

Note: Although the UFTP is certified to transport 10 year old fuel (Stahmer, 2013); the bases of this work assume the fuel to be on average 30 years old to align with the reference repository design (Garisto et. al., 2009).

- c) Only doses associated with road transport are assessed. Occupational dose received by workers during road transport is shown to be higher than occupational dose received during rail transport. See assessment in Appendix D. The transport crew accompanying a road shipment is in closer proximity to the package during transport than for similar transport by rail.
- d) The road conveyance consists of a tractor and trailer loaded with a single UFTP. An annual total of 620 shipments is assumed.
- e) Each used fuel shipment cycle consists of two transport segments: the outbound segment where the UFTP loaded with used fuel is transported from the reactor sites where it is currently stored to the repository site; and the inbound segment where the empty package is returned to the point of origin. Only outbound (loaded) segments are assumed to contribute to occupational dose (an empty UFTP does not emit radiological dose).
- f) Only normal conditions of transport, as defined by the transportation regulations (CNSC, 2000a) and (IAEA, 2000), are considered. Normal conditions of transport are intended to cover situations in which the package is subjected to minor mishaps or incidents ranging in severity, but would continue its journey after having been subjected to these minor mishaps.
- g) Only workers within a 30 m radius of the package are considered. See Appendix A.
- h) The dose rates at various distances from the UFTP are calculated in the generic transportation dose assessment (Batters et al., 2012). Reference fuel with two burnup rates are considered: 220 and 280 MWh/kgU. All used fuel bundles within the UFTP are assumed to have the identical burnup. Used fuel with an average burnup of 220 MWh/kgU is used in annualized dose calculations (assuming peak burnup fuel in annualized calculations would result in higher than realistic calculated dose). Used fuel with a peak burnup of 280 MWh/kgU is used in dose calculations for single occurrence activities to ensure conservative dose estimates. Burnup is described in greater detail in Section 3.1.1 (b).

2. RADIATION AND RADIOLOGICAL REGULATORY CONTEXT

2.1 Radiation

Radiation emitted by used fuel is in the form of alpha particles, beta particles, neutrons and photons (gamma rays). Alpha and beta particles are stopped by the thick steel walls of the transportation package. Hence, only gamma and neutron radiation levels at various distances from a loaded used fuel transportation package are considered.

Radiation dose, measured in sieverts (Sv), is a measure of the energy absorbed by human tissue and is generally used as an indicator of the potential radiation effect on the human body. Dose rate is the measurement of radiation exposure over a period of time. The dose rate (dose received during a given amount of time) decreases as the distance from the source increases or as protective shielding is added.

2.2 Regulatory Context

In Canada, the CNSC sets radiological dose limits to protect the health and safety of persons. This is done by following the recommendations of the International Commission on Radiological Protection (ICRP), which comprises some of the world's leading scientists and other professionals in the field of radiation protection, and by using many of the standards and guides of the International Atomic Energy Agency (IAEA).

Dose limits are established for:

1. a member of the general public
2. a *nuclear energy worker*, defined as a person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public (Nuclear Safety and Control Act, S.C. 1997, c.9)

2.2.1 Regulatory Dose Limits

Effective dose limits for the public and nuclear energy workers have been set by the Radiation Protection Regulations (CNSC, 2000b) and are shown in Table 1, below. For the purpose of this assessment, doses to workers are compared (if required) to a dose limit of 20 mSv per year for NEWs (i.e., the regulatory dose limit of 100 mSv averaged over five years for Nuclear Energy Workers).

Table 1: Regulatory Effective Dose Limits

Person	Period	Effective Dose
Nuclear energy worker, including a pregnant nuclear energy worker	(a) One-year dosimetry period	50 mSv
	(b) Five-year dosimetry period	100 mSv
Pregnant nuclear energy worker	Balance of the pregnancy	4 mSv
A person who is not a nuclear energy worker	One calendar year	1 mSv

Source: CNSC, 2000b

2.2.2 Maximum Radiation Levels

To protect workers and the public, the transportation regulations set maximum radiation levels for transportation packages and the conveyances in which the packages are transported. Additionally, a distinction for shipments requiring *exclusive use* is made. Exclusive use (IAEA, 2000) is the term used to define shipments by a sole consignor with control over the shipment and all initial, intermediate and final loading and unloading operations. According to regulatory requirements, the UFTP is required to be shipped under exclusive use.

Maximum radiation levels for transportation packages and conveyances under exclusive use are defined as follows:

a) Maximum Radiation Levels for Transportation Packages

The radiation level at any point on the external surface of the transportation package shall not exceed 10 mSv/h (CNSC, 2000a).

b) Maximum Radiation Levels for Conveyances

The radiation level at any point on the external surface of a conveyance shall not exceed 2 mSv/h, and shall not exceed 0.1 mSv/h at a distance of 2 m from the surface of the conveyance (CNSC, 2000a).

Maximum radiation levels for the UFTP in its road configuration are illustrated in Figure 1, below.

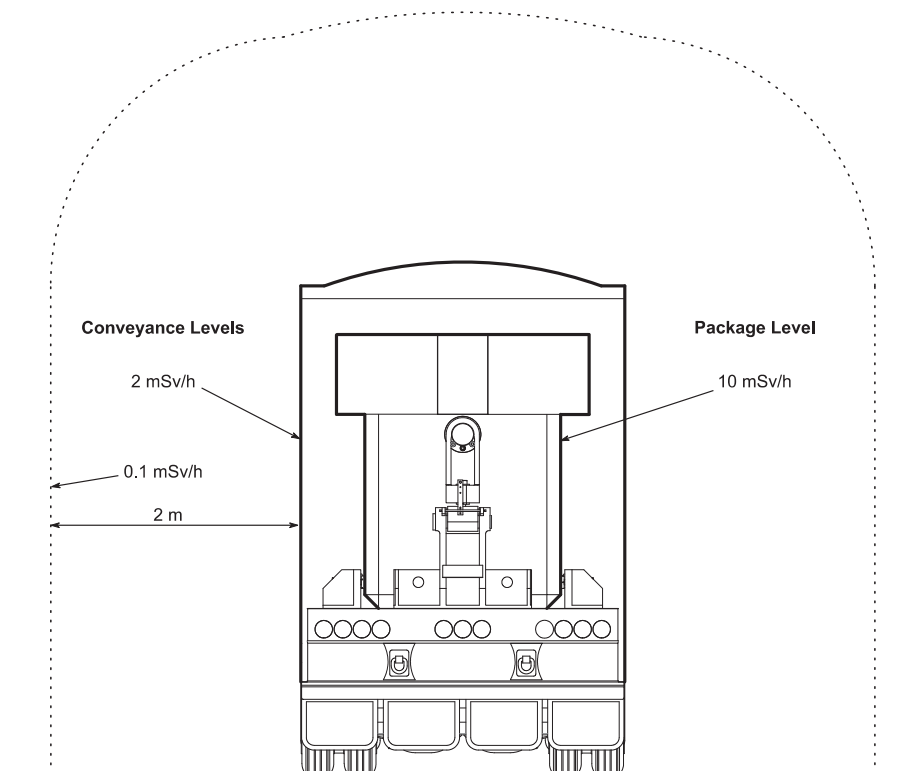


Figure 1: Maximum Radiation Levels for Packages and Conveyances Transported under Exclusive Use

3. ASSUMPTIONS AND ANALYSIS METHODOLOGY

3.1 Used Fuel Transportation Package

The cube shaped UFTP is designed to contain a total of 192 used fuel bundles in two stacked modules. The body and lid of the package are manufactured from Type 304L stainless steel. Both are constructed from single piece forgings or castings. The lid is bolted to the body using 32 bolts. An impact limiter made from redwood encased in a stainless steel shell is bolted to the lid of the package to protect the lid/body seal by reducing impact forces in the event of an accident. The impact limiter also serves as a thermal shield to protect the package seals during a fire. An illustration of the UFTP is provided in Figure 2.

The overall package dimensions are 1881 x 1556 x 1824 mm (excluding impact limiter, protrusions and attachments) and the package and impact limiter weigh approximately 35 tonnes when fully loaded with used fuel. The two long walls are 272 mm thick and the base, lid, and short walls are 267 mm thick. The package can be lifted using trunnions on either side of the body and the lid is lifted via a central flange. The package design incorporates a vent port in the lid and a drain port in the body. Both ports are sealed with a plug and a cover during transport.

The UFTP was designed, tested, manufactured by Ontario Hydro (now Ontario Power Generation) in the mid 1980's. The package design was first certified in the 1980's by the Atomic Energy Control Board (the predecessor of the CNSC). In July 2013, the package design was re-certified to meet current Canadian regulations (CNSC, 2013) and international standards (IAEA, 2000).

3.1.1 Used Fuel Properties

For the purpose of this assessment, all used fuel bundles inside the UFTP are assumed to be intact (undamaged) standard 37-element bundles. All used fuel bundles are assumed to have uniform decay and discharge burnup:

a) **Used Fuel Decay Time**

All fuel bundles inside the UFTP are assumed to be 30 years out-of-reactor.

b) **Fuel Discharge Burnup**

The radiation emitted by each fuel bundle after discharge from the reactor is dependent on the length of time spent in the reactor and is characterized by the fuel burnup rating. Burnup is a measure of how much fission energy has been produced per unit mass of fuel. Irradiated fuel bundles with higher fuel burnup will emit more radiation.

Bundle-discharge burnups for Pickering A, Pickering B, Bruce A, Bruce B, and Darlington stations have been examined. A burnup of 220 MWh/kgU represents the highest of the average burnups at these plants (Wilk, 2013). A burnup of 280 MWh/kgU represents the 95th percentile of all discharged fuel bundles from the Pickering A, Pickering B, and Bruce A stations; and the 99th percentile of all discharged bundles from the Darlington and Bruce B stations.

The burnup for used fuel from Gentilly 2 and Point Lepreau stations is generally below 190 MWh/kgU (Wilk, 2013), and hence is bounded by the OPG/Bruce Power values.

For the purposes of this assessment, the average burnup of 220 MWh/kgU is assumed for dose calculations involving multiple annual occurrences (e.g. driver dose). For single occurrences (i.e., a mechanic changing a tire en-route), the more conservative peak burnup of 280 MWh/kgU is used in the dose calculations.

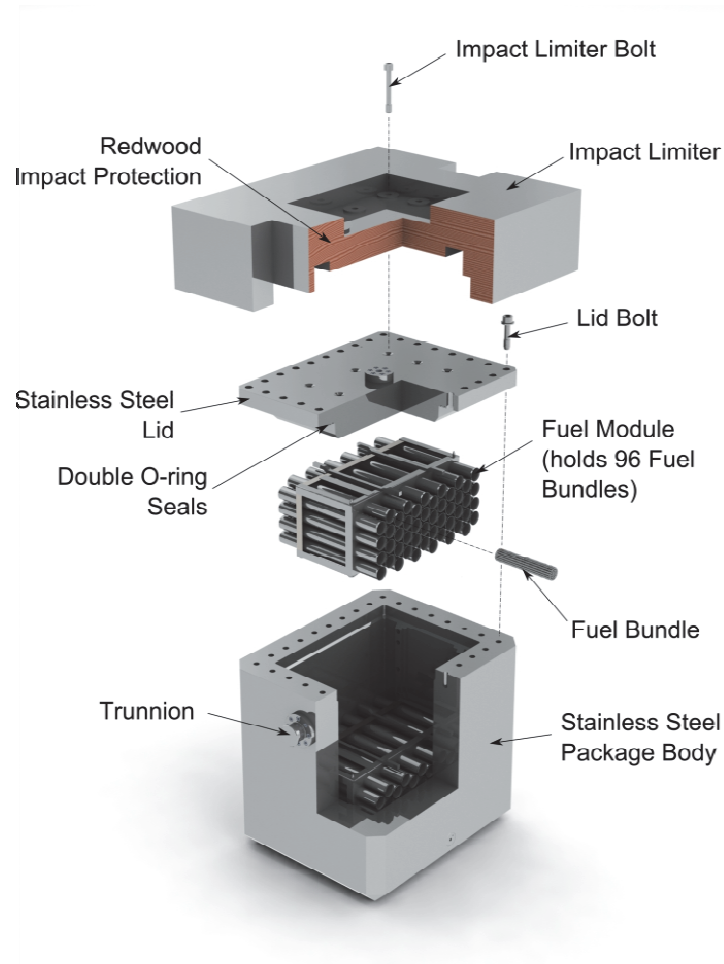


Figure 2: UFTP Assembly

3.1.2 Weather Cover (Neutron Shield)

The stainless steel construction of the UFTP provides a very effective shield for gamma radiation; however, it is less effective for shielding neutrons. Although the radiation levels for the UFTP design are below the maximum radiation levels for transportation packages, a neutron shield (doubling as a weather cover and subsequently referred to as such) could be added over top of the package to reduce radiological exposure to the public and workers. Dose rates from the UFTP have been calculated with and without a weather cover in place. The weather cover is assumed to be a 10 cm thick high-density polyethylene cover placed over top of the UFTP during transport operations.

3.1.3 Road Transport Configuration

For transport by road, the assumed configuration consists of a single UFTP on a tractor-trailer unit. The long walls of the UFTP are parallel to the direction of travel and the short walls are in line with the ends of the truck.

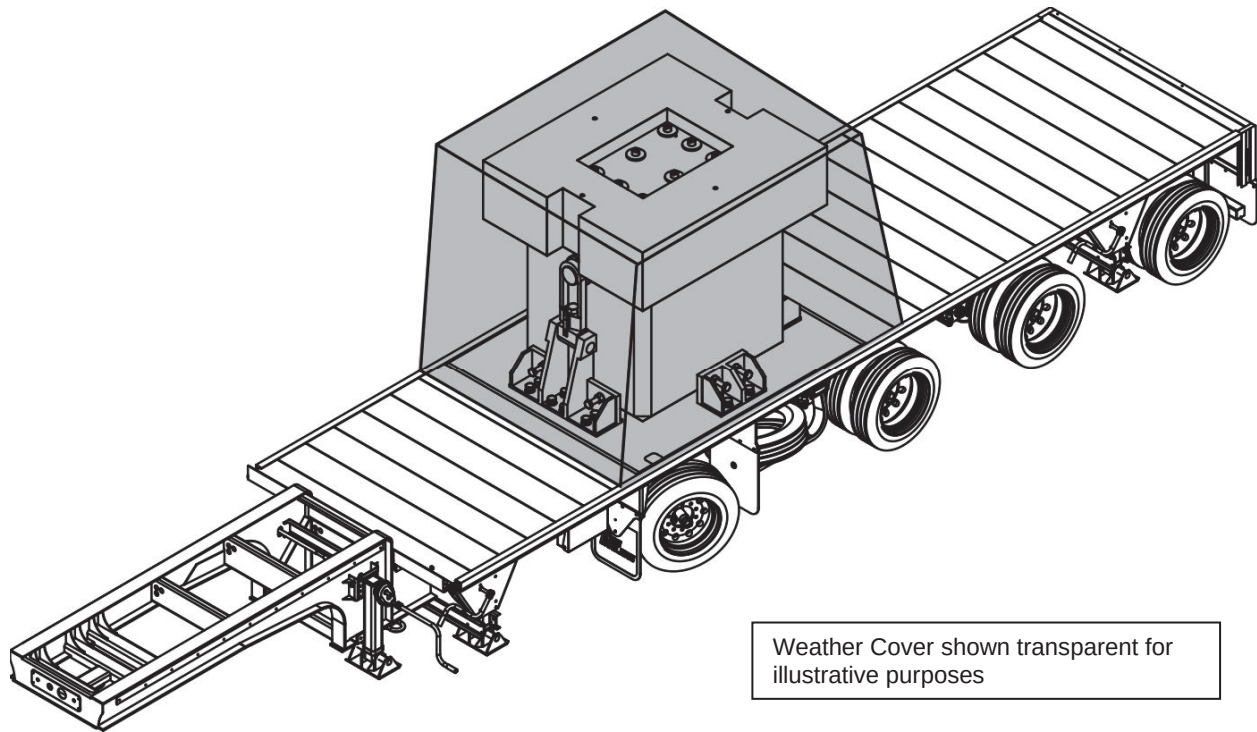


Figure 3: Typical Road Transport Configuration

The weight of the fully loaded UFTP is such that only one package can be transported on a tractor-trailer unit at a time and still comply with provincial transportation regulations in Ontario. The semi-trailer configuration consisting of a single UFTP underneath a weather cover (shown transparent for illustrative purposes) is illustrated in Figure 3. The used fuel processing facility at the repository site is designed to handle approximately 120,000 used fuel bundles per year requiring approximately 620 road shipments per year.

3.2 UFTP Dose Rates and Maximum Radiation Levels

Dose rates at various locations and distances from the UFTP were calculated in the Generic Transportation Dose Assessment (Batters et al., 2012) using a representative model of the package and the three-dimensional Monte Carlo N-Particle transport code MCNP5 (LANL, 2003).

Dose rates emitted by a UFTP filled with 192 bundles of used fuel were calculated for an average burnup of 220 MWh/kgU and peak burnup of 280 MWh/kgU. These are compared to the maximum radiation levels described in Section 2.2.2.

- For used fuel with average burnup (220 MWh/kgU), the calculated UFTP dose rate on contact is 0.061 mSv/h. This dose rate is significantly less than the 10 mSv/h level on contact for exclusive use.
- For used fuel with peak burnup (280 MWh/kgU), the calculated UFTP dose rate on contact is 0.10 mSv/h. This dose rate is significantly less than the 10 mSv/h level on contact for exclusive use.

- The conveyance includes a tractor-trailer carrying a single UFTP with a weather cover. Its dose rates would be bounded by the equivalent dose rates calculated for the package. The maximum calculated dose rates from the UFTP on contact (0.1 mSv/h) and at distance of 2 m (0.0033 mSv/h) are below the maximum radiation levels for a conveyance.

Table 2: Maximum Dose Rates from UFTP (without Weather Cover)

Distance from Package	Maximum Radiation Level (mSv/h)	UFTP	
		220 MWh/kgU	280 MWh/kgU
Contact	2 (conveyance)	0.061 mSv/h	0.10 mSv/h
	10 (exclusive use package)		
1 m	-	0.014 mSv/h	0.026 mSv/h
2 m	0.1 (conveyance)	0.0024 mSv/h*	0.0033 mSv/h*

* Note: Conveyance values at 2 m include a weather cover

3.2.1 Maximum Dose Rates

It was found that the maximum dose rates occur at the mid-height of the short side of the package; thus, to be conservative, these dose rates are used in occupational dose calculations.

The dose rates at various distances measured from the UFTP exterior surface where the maximum dose rate is found are tabulated in Table 3 below and graphed in Figure 4 and 5. The external surface of the weather cover is assumed to be approximately 0.4 m from the external surface of the UFTP.

Table 3: Dose Rates from UFTP

Distance from Package	220 MWh/kgU burnup			280 MWh/kgU burnup		
	Neutron	Gamma	Total	Neutron	Gamma	Total
Contact	0.0404	0.0208	0.061	0.0852	0.0168	0.10
0.3 m	0.0245	0.0125	0.037	0.0510	0.0153	0.067
1 m	0.00799 0.000445	0.00547	0.014 0.0060	0.0166 0.000445	0.00763	0.024 0.0082
2 m	0.00275 0.00017	0.00224	0.0050 0.0024	0.00575 0.000169	0.00310	0.0089 0.0033
3 m	0.00136 0.000094	0.00114	0.0025 0.0012	0.00283 0.000091	0.00150	0.0043 0.0016
10 m	0.00015 0.000018	0.000116	0.00027 0.00013	0.000314 0.000018	0.000142	0.00046 0.00016
30 m	0.000018 0.000003	0.000012	0.000029 0.000015	0.000037 0.000003	0.000014	0.000051 0.000018

Notes:

- all dose rates are in mSv/h
- dose rates for package only are shown in plain text.
- dose rates for package with weather cover are shown in **bold**.
- gamma dose rates include secondary gamma radiation from neutron interaction with the weather shield.

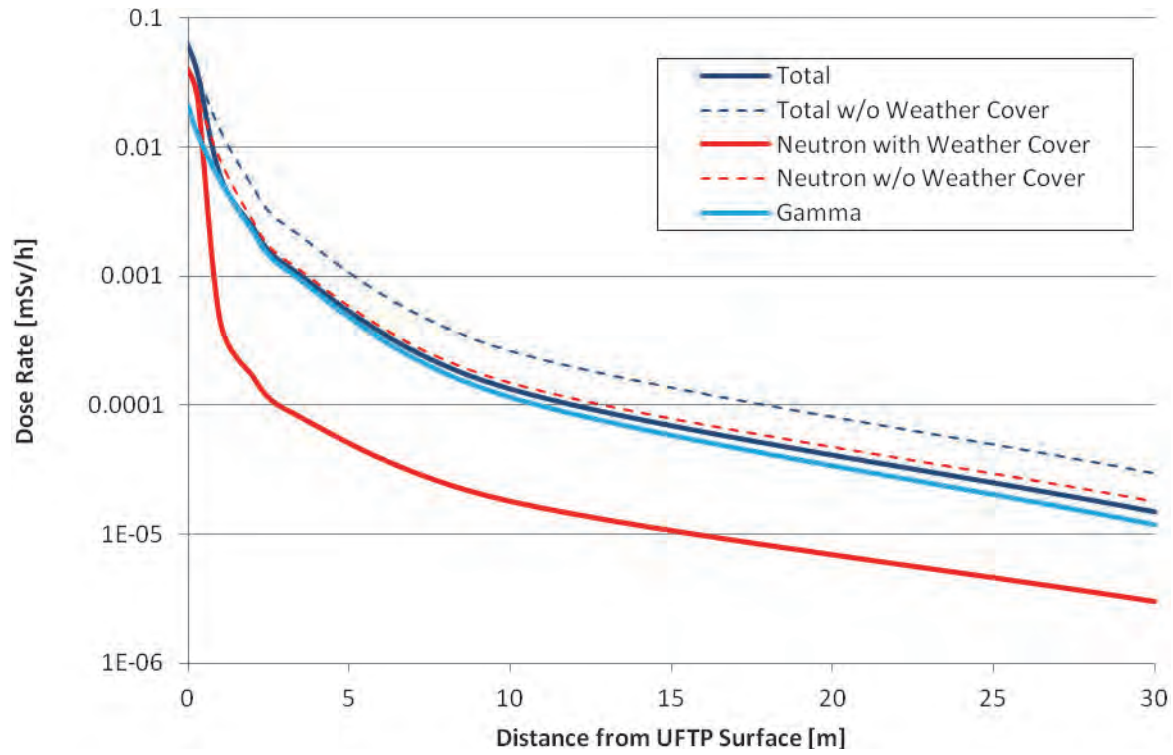


Figure 4: Maximum Dose Rates from UFTP (220 MWh/kgU)

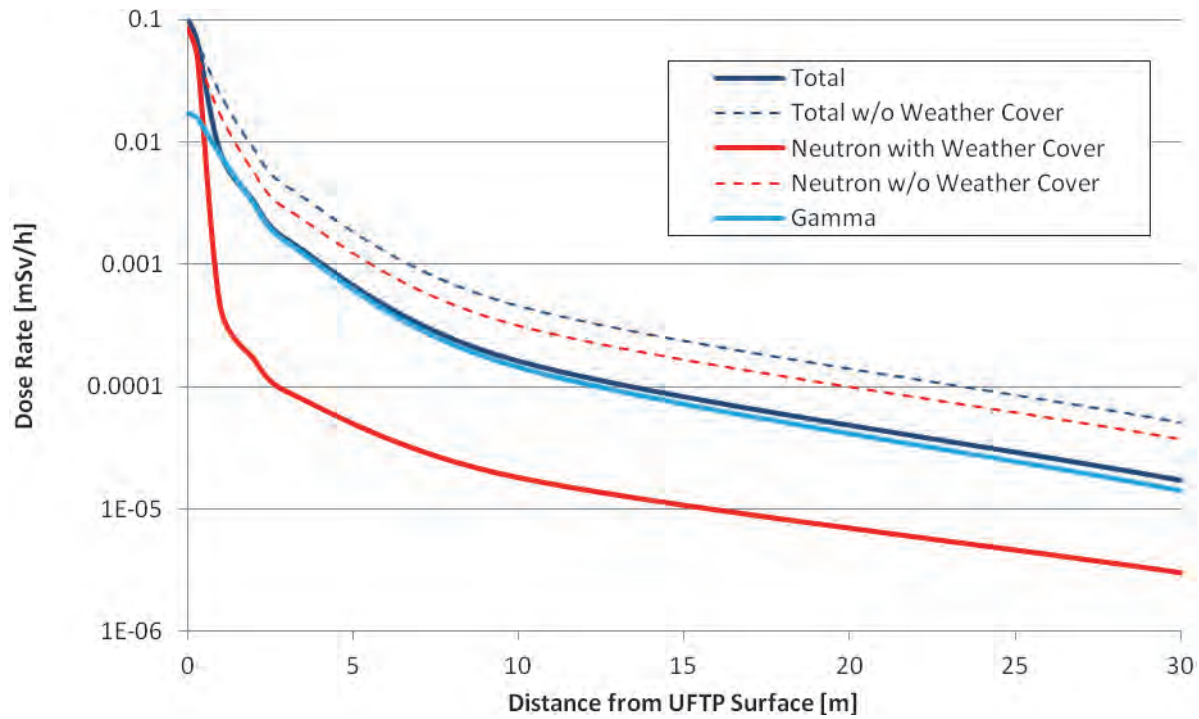


Figure 5: Maximum Dose Rates from UFTP (280 MWh/kgU)

4. TRANSPORTATION ACTIVITIES

The occupational dose due to used fuel transport is dependent on several factors which include:

- radioactivity of the radiological source (the used fuel)
- shielding present around the source (the transportation package, in this case, the UFTP)
- duration of exposure
- proximity to the radiological source
- frequency of occurrence

The first two factors, radioactivity and shielding, are determined by configuration and package design and therefore do not vary in this study. Thus differences in occupational dose for a given package configuration becomes a function of the remaining three: exposure time, distance and frequency. To calculate occupational dose, activities placing a worker in the vicinity of the package must be determined. For each activity, the activity duration, the worker's distance from the package and the frequency at which a specific activity is carried out must be established. These data are then used to calculate the dose that a worker may receive during that activity. The dose for any given activity is the product of the dose rate at the given distance, the duration of the activity at that distance, and the frequency of occurrence. The total dose the worker will receive is the sum of the doses of all activities the worker engages in. The total dose value is calculated based on a one-year period, to allow comparison with the allowable limits as shown in Table 1.

Activities associated with the transport of used fuel can be divided into three categories:

- pre-shipment activities (preparation for shipment at the interim storage site)
- activities en-route (during used fuel transport)
- activities post receipt at the eventual repository site (inspections, removal of package from trailer, etc.)

The list of activities associated with used fuel transport and the workers conducting each of these activities are itemized in Table 4 below.

Note: As stated in Section 1.2, this assessment focuses on activities associated with the physical transport of used nuclear fuel. Activities occurring at the nuclear facilities at the point of origin and destination, such as the loading and unloading of the UFTP to and from the transport vehicle, are conducted by workers within these facilities covered by the facility licences and are not part of this work.

As noted in Section 1.3 (e) above, return shipments do not contain used fuel (do not emit radiation) and thus are not considered to contribute to occupational dose.

Additionally, the scope of occupational dose calculations is limited to workers within a 30 m radius of the package. The basis for this is the calculation that a worker located at 30 m from a fully loaded UFTP during an entire 2000 hour work year would receive a dose of approximately 0.03 mSv or approximately 3% of the regulatory public dose limit or 0.15% of the dose limit for NEWs (see Appendix A).

For each activity and worker listed in Table 4 below, information was obtained from appropriate resources (such as logistics companies, mobile repair services, trucking related associations, etc.) to collect real-world time, distance and frequency scenario data in a Canadian context. These data were analyzed and used to calculate radiological dose for each activity and subsequently for each worker. Data obtained from the sources is included in Appendix B.

Table 4: Transportation Activities and Associated Workers

Pre-shipment	En-route	Upon Receipt
- connecting tractor to trailer - vehicle condition inspection - documentation check	- time in transit (driving) - vehicle inspections by driver - rest / relief stops - refuelling stops - en-route transport inspections (weigh scales) - breakdown stops – minor en-route repair / tire change	- disconnect tractor from trailer - post-shipment debrief and documentation filing
Associated Workers		
Driver	- Driver - Commercial vehicle inspector - Commercial weigh scale operator - Mechanic / tow truck operator	Driver

4.1 Driver

As stated in CNSC Regulatory Guide G-208, Transportation Security Plans for Category I, II or III Nuclear Material (CNSC, 2003), the transport crew required for a used nuclear fuel shipment consists of, as a minimum, a driver and an escort. The driver is responsible for the operation of the vehicle and the escort is responsible for on-board communications and surveillance of the shipment. For this study the driver and the escort are assumed to travel in the tractor cab.

During driving and rest stops, the transport crew is assumed to be equidistant from the UFTP. However, non-driving activities performed by the driver, such as connecting and disconnecting the trailer, conducting en-route vehicle condition inspections and refuelling the tractor routinely place the driver in closer proximity to the UFTP than the escort. During these activities, the driver will receive a greater dose than the escort. In reality, some of the driver's activities may be shared by the transport crew.

At this early stage in transport logistics planning, determination of the exact activities of the escort and any work sharing that may occur is premature. However, it is safe to assume that the dose received by the escort will not exceed the dose received by the driver. For calculation purposes, only the dose to the driver is assessed.

Dose received by the driver is a function of pre- and post-shipment activities, number and duration of the stops along the route, and the time spent driving. As the eventual repository site is still unknown, a spectrum of trip lengths is considered. Each of the activities conducted by the driver is described in more detail below. In this assessment, the driver is assumed to be assigned to the same return trip, i.e.: Darlington to Schreiber, over a one year period.

4.1.1 Pre-Driving Activities

Based on the information provided by the carriers interviewed, pre-shipment activities for the driver have been categorized into 3 groups:

a) Connecting the tractor and trailer

Connecting the tractor to the trailer includes the following activities:

- checking the 5th wheel on the tractor to ensure it is sufficiently lubricated (this activity is conducted prior to arrival).
- backing the tractor under the trailer to engage and lock the kingpin and the 5th wheel together
- ensuring that a positive connection has been made
- applying tractor brake
- inspecting the kingpin and 5th wheel and ensuring the release arm has moved into the locked position
- attaching the glad-hands (airlines) and electrical connections
- raising the landing gear

This activity typically takes 5 minutes. Additional details on the position of the driver are provided in Appendix B-1 under the activity “Tractor-Trailer Hookup / Unhook”.

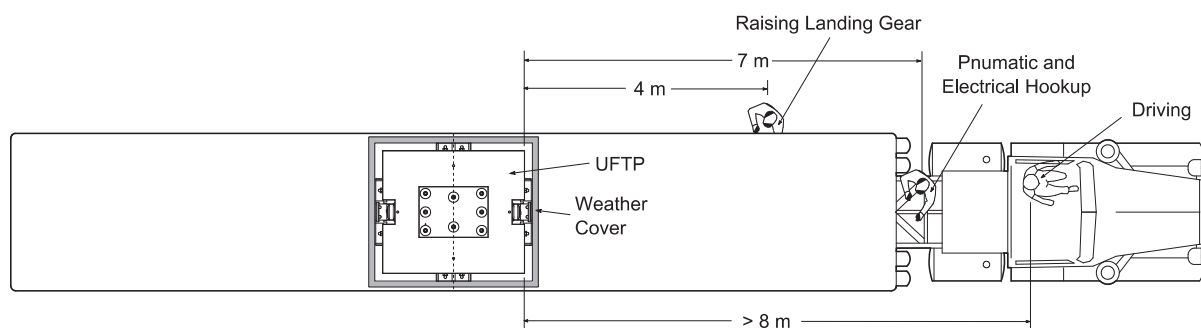


Figure 6: Driver Connecting Tractor to Trailer

b) Vehicle Condition Inspection

After hookup, the driver conducts a circle check of the vehicle. This check consists of a general condition inspection of the vehicle including: correct load securement, placards and labels, lights operational, etc. The vehicle condition inspection typically takes 10 minutes. Additional details on the position of the driver are provided in Appendix B-6 under the activity “Vehicle Inspections”. Note: any more detailed inspection of the vehicle prior to departure such as a full Commercial Vehicle Safety Alliance (CVSA) Level VI inspection (specific to radioactive materials shipments) is assumed to be conducted by a qualified inspector, and not by the driver.

c) Documentation Check

Prior to departure, the driver is briefed by the transportation staff and the driver checks the documentation accompanying the shipment, as required. This activity typically takes 15 minutes and could take place away from the loaded trailer. For calculation purposes, the driver is assumed to be in the tractor cab during this time (to maximize dose to the driver).

4.1.2 En-route Activities

4.1.2.1 Driving

Driving time must be established to estimate radiological dose to the driver. The time required to complete one shipment cycle (a round trip shipment – UFTP loaded with used fuel from the interim storage site to the repository and an empty UFTP on the return trip) is the sum of times for all activities performed by the driver over the course of the trip.

a) Transport Crew Location

The NWMO UFTP Mobile Display tractor-trailer configuration is assumed to be typical of the configuration that will be used once transport operations begin. In this configuration, the distance between the package and leading edge of the trailer is 6.6 m as shown in Figure 7, below. Tractors with sleeper units behind the driver are typically longer than those without, placing drivers at a further distance from the UFTP. In the existing UFTP mobile exhibit tractor-trailer unit, the distance between the front wall of the UFTP and the rear wall of the tractor sleeper berth is approximately 8 m. Conservatively, for calculation purposes, the transport crew is assumed to be located at 8 m from the UFTP. No credit is given for any shielding provided by the sleeper or tractor walls. Additional details on the position of the driver are provided in Appendix B-5 under the activity “En-route Transport”.

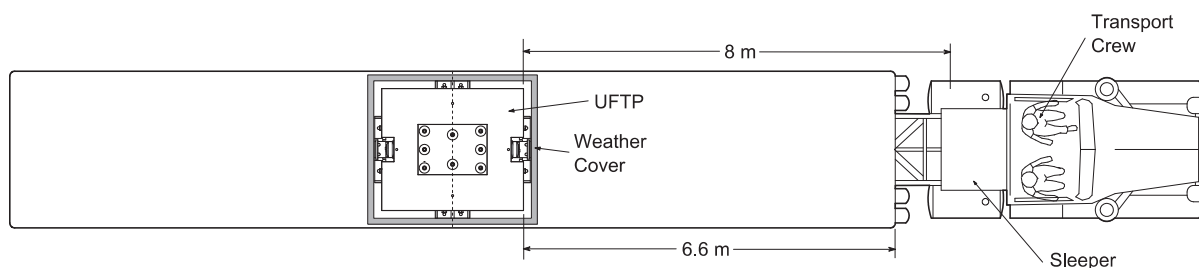


Figure 7: Transport Crew in Tractor Cab during Driving

b) Trip Length

As the repository site location is unknown, various trip lengths are considered. Eleven communities are currently in the site selection program (one in Saskatchewan, one in Ontario west of Thunder Bay, four between Thunder Bay and Sault Ste. Marie, two near Elliot Lake, and three in southwestern Ontario). To characterize transport between the interim storage locations and these communities, six representative trip lengths ranging from 50 km to 2900 km are considered. These trip lengths, detailed further in Section 4.1.2.2, have been selected to represent typical distances from the existing interim storage sites to potential repository sites. For calculation purposes, five of the trips assume the representative point of origin to be the Darlington nuclear facility, as transport from Darlington maximizes travel through densely populated areas. The 6th trip assumes the trip origin to be the Bruce Nuclear facility and the destination a representative site in southwestern Ontario approximately 50 km away.

c) Population Density

Transport speed along a road or regional highway is dependent to a degree on the population density of the area through which the road travels. For example, rural highway speed limits are often reduced in areas where the highway passes through a town. To account for this, population centres along representative trips are examined.

Statistics Canada defines, “A population centre as area with a population of at least 1,000 and a density of 400 or more people per square kilometre. All areas outside population centres will continue to be defined as rural area.” (Statistics Canada, 2011). However, these two divisions are too broad for the purposes of this investigation.

To account for the numerous small towns with populations less than 1000 and posted speed limits less than highway speed, population densities in this assessment have been broken into three ranges: urban, suburban and rural. These densities were selected to allow identification of areas of reduced speed limits along roadways (see Figure 8). The population densities are classified as:

- Urban: more than 650 persons per km²
- Suburban: 50 to 650 persons per km²; and
- Rural: less than 50 persons per km².

This division is similar to the population density classifications used in the radiological assessment code RADTRAN (Weiner et al., 2009). Note that the suburban range (50 to 650 persons per km²) straddles Statistics Canada’s value of 400 persons per km² for the urban/suburban boundary.

Population densities in Ontario were obtained using Statistics Canada data from the 2011 census (Statistics Canada, 2011). A map showing the population densities in Ontario is provided in Figure 8.

Each trip is broken down into segments based on the population density zone it passes through. The distance of each segment is calculated and an associated transport speed is assigned. For each trip, the total distance through each population density zone is determined.

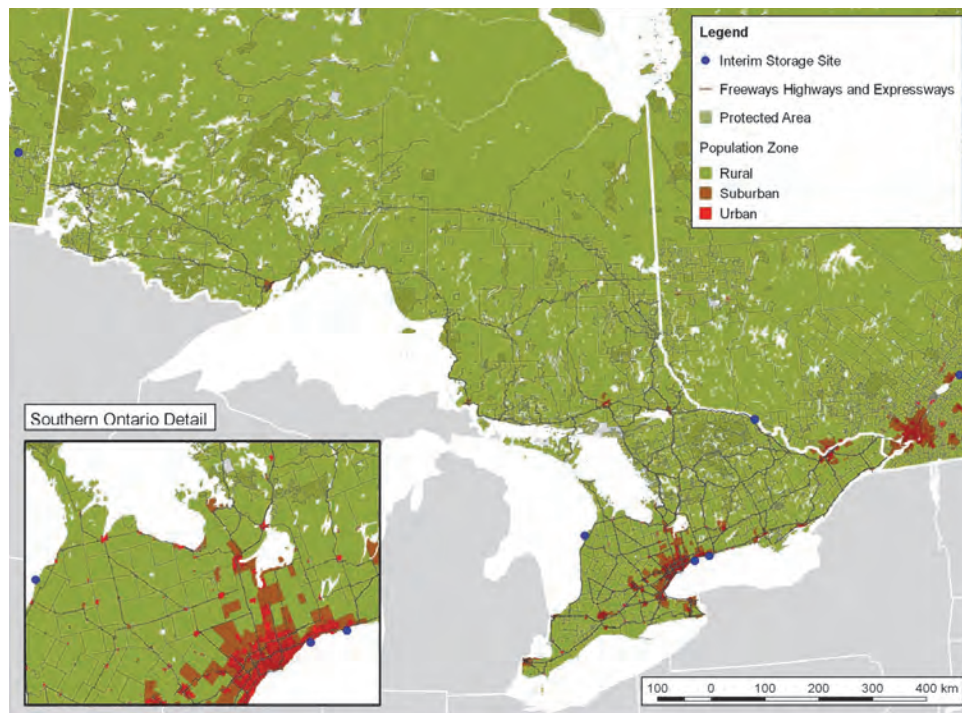


Figure 8: Sample Population Density Zone Map

d) Transport Speed in Population Density Zones

Typical posted transport speed limits through population density zones are provided in Table 5 below. Although use of highways is assumed (controlled access highways through large population areas), average transport speeds are frequently lower than the posted speed limits due to traffic congestion. For example, the average speed of commuting through Toronto is 42 km/h (Metrolinx, 2008), hence this speed is assumed for all urban segments. A speed of 45 km/h is assumed for suburban segments and a speed of 70 km/h for rural segments. These assumptions fall within the range of average speeds published by the Transportation Association of Canada (TAC) (Kingston, 2011)

Table 5: Transport Speed Limits in Population Density Zones

Population Density	Typical Posted Speed Limit	Speed Assumed in Calculations
Urban (≥ 650 persons per km ²)	100 km/h (controlled access highway) 50 km/h (city street)	42 km/h*
Suburban (< 650 persons per km ² and ≥ 50 persons per km ²)	80 to 100 km/h (highway)	45 km/h**
Rural (< 50 persons per km ²)	80 to 90 km/h (highway)	70 km/h**

* Reference: Metrolinx, 2008

** Reference: Kingston, 2011

e) Transport Distance and Time

For each trip, distances through the three population density zones: urban, suburban and rural, are calculated (see Table 6). The communities presented in this table are selected solely to provide a range of possible transport distances. Using the transport speeds in Table 5, the travel time in each population density zone is calculated and summed to obtain a total travel time. Note that travel time does not include stops along the route. Stops during driving are addressed in the next section.

4.1.2.2 Stops during Driving

Carriers, such as Caravan Logistics and Ontario Power Generation, were contacted to provide information on typical activities of the driver during routine trips. Frequencies of the activities were also provided. Stops are divided into three categories: rest and relief, en-route vehicle condition inspections, and refuelling. Each is described in more detail in Sections (a) to (c) below.

Table 6: Distances and Travel Times through Population Density Zones

Representative Trip	Distance	Distance and Travel Time in Zone			Total Travel Time
		Urban	Suburban	Rural	
Bruce to South Bruce	50 km	0 km	3 km	47 km	00:44 h
		00:00 h	00:04 h	00:40 h	
Darlington to South Bruce	250 km	86 km	47 km	117 km	04:45 h
		02:02 h	01:03 h	01:40 h	
Darlington to Elliot Lake	600 km	82 km	64 km	454 km	09:51 h
		01:57 h	01:25 h	06:29 h	
Darlington to Schreiber	1200 km	89 km	83 km	1028 km	18:38 h
		02:07 h	01:50 h	14:41 h	
Darlington to Ignace	1700 km	99 km	98 km	1503 km	26:00 h
		02:21 h	02:11 h	21:28 h	
Darlington to Creighton	2900 km	102 km	139 km	2659 km	43:30 h
		02:26 h	03:05 h	37:59 h	

a) Rest and Relief Stops

Rest and relief stops are required during any lengthy journey. Based on information provided by commercial trucking firms, rest and relief stops are typically 30 minutes in length and are made approximately every 400 km or 4 hours of driving time. All trips greater than 300 km in length are assumed to have at least one stop for rest or relief (Note: it is assumed that rest stops are not taken during 50 km and 250 km shipments). As traffic congestion and unplanned traffic slowdowns or stoppages cannot be predicted, for dose calculation purposes, rest and relief stops are based on travel distance and not driving time.

Although it is expected that each member of the transport crew will leave the tractor cab over the course of the stop, for dose calculation purposes, the driver is assumed to remain in the tractor cab during each rest stop for its entirety (to maximize dose to the driver). Additional details on the position of the driver are provided in Appendix B-3 under the activity "Rest / Relief Stop".

b) En-route Vehicle Condition Inspections

Regulations require that the condition of a commercial vehicle is monitored by the driver during transport. This requirement is met through en-route vehicle condition inspections. These inspections carried out by the driver are typically conducted every 200 km and are similar to the pre-shipment vehicle condition inspection discussed in Section 4.1.2 (b) (Note: it is assumed that there are no en-route vehicle inspection stops for trips less than 300 km in length). Additional details on the position of the driver are provided in Appendix B-5 under the activity "Vehicle Inspections". For dose calculation purposes, the driver is assumed to conduct all vehicle condition inspections, placing him or her in close proximity to the package more frequently than any other transport crew member.

c) Refuelling Stops

Refuelling stops of a tractor-trailer loaded with used nuclear fuel should be kept to a minimum. It is assumed that the fuel tanks on the tractor are full at the point of origin. The range of a

tractor-trailer is approximately 1400 km, thus only trips greater than 1400 km in length will require refuelling. The time to refuel takes approximately 20 minutes.

Refuelling is assumed to take place at a commercial cardlock station such as the one shown in Figure 9. Cardlock stations can support the refuelling of multiple vehicles at the same time. The assumed configuration of the cardlock station along with the time and distance assumptions used in the dose calculations is presented in Appendix B-4. For calculation purposes, the driver is assumed to be located 6 m from the UFTP during refuelling.



Figure 9: Commercial Cardlock Station on Highway 17

4.1.3 Post-Driving Activities

Upon arrival at the destination, the driver disconnects the tractor from the trailer. This is essentially the reverse of the activities listed in Section 4.1.1 (a) and requires the same amount of time (5 minutes). Last, the driver prepares documentation for filing into a records management system and is debriefed by the transportation manager. This activity typically takes 15 minutes and would typically take place away from the trailer. For calculation purposes, this is assumed to take place at 8 m from the UFTP (to maximize dose to the driver).

4.1.4 Driver Activity Summary

a) Pre- and Post-Driving Activity Summary

The calculation of total driving time includes pre- and post-shipment activities. Typical activities for the driver detailed in Appendix B are summarized in Table 7 below. Typically, pre-shipment activities performed by the driver require 30 minutes and post-shipment activities require 20 minutes.

Table 7: Pre- and Post-Shipment Activities

Activity	Duration	Performed by
Tractor Hookup to Trailer	5 min	Driver – Pre-Shipment
Vehicle Condition Inspection	10 min	Driver – Pre-Shipment
Documentation Preparation and Check	15 min	Driver – Pre-Shipment
Unhook Tractor from Trailer	5 min	Driver – Post-Shipment
Documentation Submission and Debrief	15 min	Driver – Post-Shipment

b) En-route Activity Summary

Parameters used to determine the number of and total time for stops along the trip are summarized in Table 8 below.

Table 8: Stop Durations and Frequencies

Stop Type	Duration	Frequency
Rest / Relief	30 min	Every 400 km or 4 hours All trips over 300 km have at least one rest stop
Vehicle Condition Inspection	10 min	Every 200 km for trips greater than 300 km
Refuelling	20 min	Every 1400 km

4.1.5 Time per Shipment and Maximum Annual Shipments per Driver

The total time per shipment includes the times for pre- and post-shipment activities, all stops and time in transit. Shipment times for each of the 6 representative trips are summarized in Table 9, below.

Used fuel delivery from the reactor sites where it is currently stored to the repository site will require approximately 620 UFTP shipments per year. Using the representative trip lengths presented in Table 6, a given driver is only able to perform a fraction of this total. The maximum number of annual shipments for a given driver can be estimated by dividing the number of available work hours by the total time for a return shipment (a 2000 hour work year is assumed: 40 working hours per week, 50 weeks per year) and is presented in Table 9. In the case of the 50 km trip (Bruce site to repository site in Southwestern Ontario), the maximum number of annual trips is calculated to be 636. However, current transport logistics estimates (Stahmer, 2009) indicate that the maximum number of annual shipments originating from the Bruce site is 295. In this case, the number of annual shipments for the driver has been reduced from the calculated number (636) to the number provided in current transport logistics estimates (295).

Due to hours of service requirements, trips over 600 km in length may require multiple drivers or overnight stops. Addressing of these logistics decisions is premature and out of scope for this analysis; however, trip length has minimal impact on annualized driver dose. See Section 6.1.1 for discussion on data sensitivity.

Table 9: Maximum Annual Shipments per Driver

Activity	Trip Length					
	50 km	250 km	600 km	1200 km*	1700 km*	2900 km*
Pre-Shipment	00:30 h	00:30 h	00:30 h	00:30 h	00:30 h	00:30 h
Rest / Relief Stops	00:00 h (0 stops)	00:30 h (1 stop)	00:30 h (1 stop)	01:30 h (3 stops)	02:00 h (4 stops)	03:30 h (7 stops)
Vehicle Condition Inspection Stops	00:00 h (0 stops)	00:00 h (0 stops)	00:20 h (2 stops)	00:50 h (5 stops)	01:20 h (8 stops)	02:20 h (14 stops)
Refuelling Stops	00:00 h (0 stops)	00:00 h (0 stops)	00:00 h (0 stops)	00:00 h (0 stops)	00:20 h (1 stop)	00:40 h (2 stops)
Driving Time	00:44 h	04:45 h	09:51 h	18:38 h	26:00 h	43:30 h
Post-Shipment	00:20 h	00:20 h	00:20 h	00:20 h	00:20 h	00:20 h
Total Time per Shipment (one way)	01:34 h	06:05 h	11:31 h	21:48 h	30:30 h	50:50 h
Maximum Annual Shipments	295**	164	86	45	32	19

* Multiple drivers or overnight stops will be required to meet Hours of Service requirements.

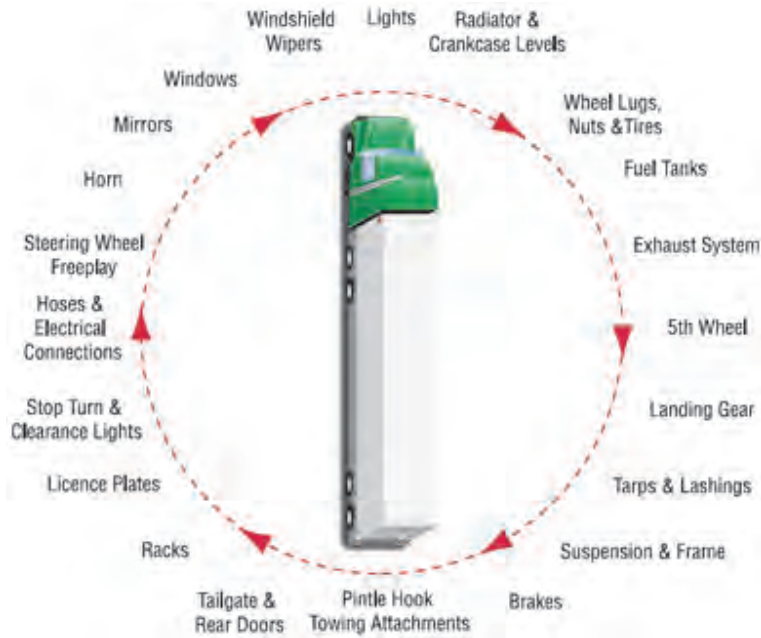
** The number of annual shipments originating from the Bruce site. See NWMO TR-2009-21.

4.2 Provincial Commercial Vehicle Inspector

Provincial commercial vehicle inspectors ensure that commercial vehicles are in compliance with acts, regulations and safety standards. Their role is to visually inspect vehicles and load securing systems to look for defects. They also review documentation, inspect driver licenses and log books, examine commercial vehicle licenses, insurance documents, and permits for compliance with applicable acts and regulations.

Through the Commercial Vehicle Safety Alliance (CVSA), commercial vehicle inspections have been harmonized between provinces. There are several levels of inspection ranging from a comprehensive (Level I) inspection that evaluates both the driver and vehicle, to ones with a more specific area of focus, such as for hazardous or radioactive materials (Level VI). Inspections and affixing of CVSA decals must be performed by certified inspectors. The term "certified" means the government employee performing inspections and/or affixing CVSA decals must have successfully completed a training program approved by the CVSA.

Vehicle inspections typically follow a similar pattern termed the circle check (see Figure 10). Inspection durations will vary depending on the comprehensiveness of the inspection, but the inspection consists of an inspector walking around the conveyance, and at times, going underneath and on to the vehicle deck to inspect the various components and features (e.g. brakes and tie-downs).



Source: Ontario Ministry of Transportation (MTO)

Figure 10: Commercial Vehicle Circle Check

Dose received by the inspector during the inspection will vary depending on the level of inspection being conducted. Data provided by the Ontario Ministry of Transportation (MTO) indicates that approximately 110,000 commercial vehicle inspections are conducted by government inspectors annually. Details on the proximity and duration of the inspector to the vehicle for the different inspection levels are provided in Appendix B-6 under the activity "Vehicle Inspections".

4.3 Commercial Weigh Scale Operator

Regulations require that commercial vehicles be weighed periodically. Weighing typically takes place at either government or commercial weigh stations along highways, but may also be performed en-route by ministry inspectors using portable scales.

During the weighing, a weigh scale operator may be in proximity of a loaded UFTP. With information provided by the MTO, placement of weigh scale operators was established for both stationary and portable scales. Dose received by the weigh scale operator will vary depending on the type of scale being used to weigh the vehicle. A typical stationary weigh scale configuration is shown in Figure 11 below. Additional details for the different scale configurations are provided in Appendices B-7 and B-8 under the activities "Weighing at Weigh Station" and "Weighing with Portable Weigh Scale".

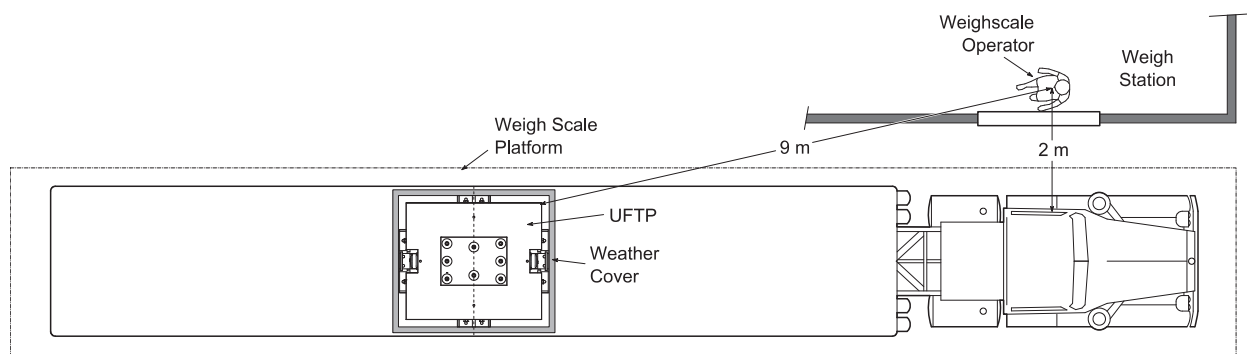


Figure 11: UFTP Shipment in Stationary Weigh Scale

4.4 Mechanic – Mobile Repair Service Operator

UFTP transportation equipment will be maintained to the highest standards and will be inspected prior to departure as well as en-route and upon arrival at the destination. However, breakdowns of equipment may occur. Mobile repair services will be at times required to fix flat tires or make minor repairs to the tractor-trailer while it is en-route. Depending on the nature of the breakdown, the repair work may place a mechanic or tow truck operator close to a loaded UFTP.

Mobile breakdown services were contacted and typical repairs that may be required during transit were established. Replacement of the inner tire of a dual tire group and the repair of a maxipot brake chamber were considered to be typical roadside repairs. In either case, the repair time and distance from the UFTP is assumed to be similar. For the dose calculations, the mechanic is assumed to be located at a distance of 0.4 m away from the UFTP during the duration of the repair. For a given mechanic, this scenario is assumed to be a singular event. Additional details are provided in Appendix B-9 under the activity “Minor Breakdown or Tire Repair”.

5. ILLUSTRATIVE OCCUPATIONAL DOSE

Calculation of individual dose to a worker for a given scenario is the product of the dose rate at the distance defined in the scenario, the exposure time and frequency. The relative distance between the worker and UFTP is assumed to be fixed during this time.

For example, from Table 3, the dose rate at 10 m from the package and weather shield is 0.00013 mSv/h. This means an individual standing 10 m away from the long side of the package for one hour would receive a dose of 0.00013 mSv. If the individual is present at that location for 15 minutes, they would receive a dose of 0.000033 mSv, or one quarter of the hourly dose. Likewise, an individual present at that location for 3 hours would receive a dose of 0.00039 mSv, or three times the hourly dose.

Exposure frequency must also be considered to calculate annual dose. From the example in the paragraph above, an individual located 10 m away from the long side of the package for 15 minutes receives a dose of 0.000033 mSv. Assuming the individual experiences this scenario 5 times during the span of a year, the individual then receives 5 times the dose received in the 15 minute exposure, or 0.00016 mSv per year.

As mentioned in Section 3.1.2, the weather cover provides additional shielding of neutron radiation. The weather cover is an integral part of the transportation system and the UFTP will be covered during all shipments.

There are instances where the relative motion between the worker and the UFTP are not fixed, such as a UFTP shipment passing a weigh scale operator. In cases such as this, calculation of dose to the worker differs somewhat from the calculations described above. Here the worker is assumed to be stationary at a given distance from the passing UFTP shipment. As the vehicle approaches, the dose rate the individual is exposed to will increase till it reaches a maximum when the transportation package(s) is (are) closest to the individual. The dose rate then decreases as the vehicle continues on its route. The total dose received is dependent on vehicle speed; the faster the vehicle speed, the lower the dose because of the reduced exposure time. This methodology is discussed in more detail in Appendix C.

5.1 Driver

Driver dose is the sum of doses received during pre-shipment, en-route and post-shipment activities. These activities are dependent on many factors including traffic conditions, road conditions, vehicle speed, trip length, population density, en-route condition inspection and rest stop frequencies, etc.

Table 10: Driver Dose Summary

Shipment Length	50 km	250 km	600 km	1200 km	1700 km	2900 km
Per-shipment Dose by Activity (all doses in mSv)						
Pre-shipment	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066
Driving	0.00015	0.00095	0.0020	0.0037	0.0052	0.0087
Rest Stops	0.00	0.00010	0.00010	0.00030	0.00040	0.00070
Condition Inspections	0.00	0.00	0.0012	0.0029	0.0046	0.0081
Refuelling	0.00	0.00	0.00	0.00	0.00012	0.00023
Post-Shipment	0.000088	0.000088	0.000088	0.000088	0.000088	0.000088
Per-Shipment Dose	0.0009	0.0018	0.0040	0.0077	0.011	0.018
Annual Dose by Activity (all doses in mSv)						
Pre-shipment	0.20	0.11	0.057	0.030	0.021	0.013
Driving	0.044	0.16	0.17	0.17	0.17	0.17
Rest Stops	0.00	0.016	0.009	0.014	0.013	0.013
Condition Inspections	0.00	0.00	0.099	0.13	0.15	0.15
Refuelling	0.00	0.00	0.00	0.00	0.004	0.004
Post-Shipment	0.026	0.014	0.008	0.004	0.003	0.002
Annual Dose	0.27	0.30	0.34	0.34	0.35	0.35

Note: All doses rounded to 2 significant digits.

Each driver activity was identified and assessed individually to determine driver location and time. This data was then used to calculate the maximum number of shipments a driver could make in a given year. Once this was established, per-shipment and annual dose to the driver was calculated. The results for the 6 different trip lengths discussed in Section 4.1.2.1 are summarised in Table 10 above. Detailed calculations and assumptions for each activity are presented in Appendix B-1 through B-4 and are summarized in Appendix B-5.

5.2 Commercial Vehicle Inspector

Vehicle inspection standards are established by the CVSA and compliance inspections are conducted, in Ontario, by the Ministry of Transportation (MTO). Inspections typically consist of a circle check of the vehicle placing the inspector at various distances from the package during the course of the inspection. Inspections to the various CVSA levels range in completion time from approximately a half-hour for a CVSA Level II inspection to one-and-a-half hours for a CVSA Level VI inspection.

To address the issue of varying distance from the package, the area around the vehicle was divided into 1 m² parcels and the inspector was assumed to be in each of the 46 parcels an equivalent amount of time. This methodology is described in further detail in Appendix B-6 and was applied to all vehicle inspections, both CVSA and en-route vehicle condition inspections performed by the driver.

Data provided by MTO indicates that government inspectors inspect approximately 110,000 commercial vehicles per year across all inspection levels. This is only a small fraction of the number of shipments made. For dose calculation purposes, the MTO agreed that inspection of 5% (or 31 shipments per year) of all UFTP shipments was reasonable. For additional conservatism, all of these inspections are assumed to be conducted by the same inspector.

A summary of the dose calculation results for the CVSA inspections is in provided in Table 11, below.

Table 11: Commercial Vehicle Inspector Dose

Inspection Level	Dose per Inspection [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]
CVSA Level I	0.0035	31	0.11
CVSA Level II	0.0017	31	0.054
CVSA Level VI	0.0052	31	0.16

Note: All doses rounded to 2 significant digits.

5.3 Commercial Weigh Scale Operator

Commercial vehicle scales at weigh stations vary in size. Some have scales that can only weigh axle groupings while others can weigh the entire vehicle at once. Depending on the weigh station, the time required to weigh a vehicle will vary. Additionally, Ministry inspectors have portable scales that can be used to weigh a vehicle along a roadway (see Figure 12). These variances were considered in calculating dose to a weigh scale operator.

For operators at stationary scales, the methodology applied in dose calculations was similar. The operator was assumed to be in a fixed position during the weighing activity. For a large

scale, only one fixed position (operator near tractor cab) was considered. For small scales, a second fixed position placing the operator in closer proximity with the rear axle grouping was added. In both cases, dose received during vehicle approach and departure was included (see Appendix B-7).

Weighing a vehicle using portable scales requires two scale units, one for each side of the vehicle. One axle is weighed at a time. The scales are placed on the ground in front of the wheels and the vehicle is driven forward onto the scales. The axle weight is the sum of the weights of each scale. Weighing of a tractor-trailer in this manner typically takes 15 minutes. Equal time is assumed to be required at each axle location. The dose to the inspector is calculated to be the sum of the dose received at each axle location during the total weighing activity (see Appendix B-8).



Figure 12: MTO Weigh Station and MTO Officer using a Portable Scale

Based on information provided by the Ontario Ministry of Transportation (MTO), any given operator was assumed to be present for 5% of all 620 annual shipments (31 shipments). The dose received by weigh scale operators is summarized in Table 12 below.

Table 12: Weigh Scale Operator Dose

Scale Type	Operator Dose per Weighing [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]
Stationary – Large Platform	0.0000084	31	0.00026
Stationary – Small Platform	0.000089	31	0.0028
Portable	0.00040	31	0.012

Note: All doses rounded to 2 significant digits.

5.4 Mechanic – Mobile Repair Service

Commercial trucking operators and mobile repair service providers were contacted to identify the types of breakdowns that could typically be expected to be repaired en-route: Breakdowns in two categories were identified: tire replacement and brake chamber replacement. For dose calculations, the mechanic is assumed to be positioned in close proximity (approximately 0.4 m, alongside the weather cover) of the UFTP. Roadside repairs such as these typically take between one half to 1 hour to complete. The dose received by the mechanic during the repair is calculated to be 0.017 mSv (see Appendix B-9).

6. DISCUSSION OF RESULTS

6.1 Driver

Radiological dose received by the driver for a given shipment is largely a function of shipment length. The dose received by a driver varies from 0.0009 mSv for a 50 km shipment to a dose of 0.018 mSv for a 2900 km shipment. However, as a given driver on a short route will make many more shipments during a given year than a driver on a long route, the annualized doses received by a driver end up varying very little. As presented in Table 10, the lowest dose is 0.27 mSv per year for a driver on the 50 km route while the dose for a driver on the 2900 km route is only 0.35 mSv per year.

Occupational doses to workers under normal transport conditions were estimated to be below the dose limit for a member of the public (i.e., 1 mSv per year); and, by extension well below that of 20 mSv per year for NEWs (i.e., the regulatory dose limit of 100 mSv averaged over five years for Nuclear Energy Workers).

Dose rates and resulting occupational doses received by workers have been calculated and are not based on measured values. Dose monitoring of occupational activities for drivers and security escorts will be established when the radiation protection program is developed, prior to the operational start up of the used fuel transportation program.

6.1.1 Data Sensitivity

As mentioned in Section 5.1, driver dose is dependent on many factors. To determine the sensitivity of the annualized dose to the various inputs, calculations were repeated with varying inputs. For example, the calculated dose received by a driver in the base assumption ranges from 0.27 mSv per year to 0.35 mSv per year. This assumes average transport speeds of 42 km/h for urban areas, 45 km/h for suburban areas and 70 km/h for rural areas. See Base Assumption in Table 13 below.

Recalculating driver dose using typical posted speed limits of 100 km/h for urban areas, 50 km/h for suburban areas and 80 km/h for rural areas only marginally affects the annual driver dose. For this data, the dose range is 0.25 to 0.39 mSv per year. See the column “Posted Speed” in Table 13 below.

Using typical posted speed limits of 100 km/h for urban areas, 50 km/h for suburban areas and 80 km/h for rural areas in Southern Ontario (trips of 50 and 250 km in length) and 90 km/h for rural areas in Northern Ontario and extending the rest stop length from 30 to 45 minutes in length, the dose range is 0.26 to 0.38 mSv per year. See the last column in Table 13 below.

Table 13: Data Sensitivity to Transport Speed and Rest Stop Length

	Base Assumption	Posted Speed	Posted Speed – Longer Rest Stop
Transport Speed			
Urban	42 km/h	100 km/h	100 km/h
Suburban	45 km/h	50 km/h	50 km/h
Rural	70 km/h	80 km/h	80 or 90 km/h
Rest Stop Length	30 min	30 min	45 min
Annual Driver Dose	0.27 mSv – 0.35 mSv	0.25 mSv – 0.39 mSv	0.26 mSv – 0.38 mSv

This consistency in driver dose can be readily explained. Varying the transport speed, rest stop and en-route inspection frequencies, or pre- and post-shipment activities all end up affecting the number of shipments per year. A faster shipment cycle means more shipments by the driver; a slower shipment cycle means fewer shipments. However since the length of the work year and hours of service remain fixed, the impact of dose to the driver is minimal, because the time spent by the driver in front of the package remains similar.

Conservatively, the transport crew was assumed to remain in the tractor cab during the documentation check (both pre- and post-shipment) and during all the rest stops. In reality, the crew is not restricted to remain in the cab during these activities. For all transport distances, occupational dose is dominated by dose received while performing activities other than documentation checks and rest stops. The annual dose range for the driver was unaffected when the doses were recalculated assuming virtually zero dose during these activities.

6.2 Commercial Vehicle Inspector

The potential dose to a commercial vehicle inspector varies from 0.054 mSv for an inspector inspecting 31 shipments annually to CVSA Level II standards to 0.16 mSv for an inspector inspecting 31 shipments annually to CVSA Level VI standards.

Although dose to the inspector for a singular inspection is low (two CVSA Level VI inspections are roughly equivalent to a dental x-ray (typically 0.01 mSv (Mettler, 2008))), awareness of potential dose uptake and caution are advisable for all detailed inspections. (According to CVSA, most employers require dosimeters to be worn as part of the personal protective equipment to be worn by inspectors conducting Level VI inspections. All Level VI qualified inspectors interviewed were Haz Mat qualified. The transport crew will be equipped with dose monitoring equipment and will be trained to instruct the inspector to minimize exposure by conducting work (when possible) at a greater distance from a loaded package.

In the unlikely event that more than 5% of shipments are inspected by the same inspector during a given year, the possibility exists that the dose received by that inspector may exceed the public dose limit of the dose of 1 mSv per year. The maximum number of inspections that a given inspector can perform without exceeding this limit is presented in Table 14, below.

Table 14: Maximum Inspections for a Given Inspector

Inspection Level	Maximum inspections per Inspector
Level I	289
Level II	579
Level VI	193

6.3 Commercial Weigh Scale Operator

The potential annual dose received by a weigh scale operator ranges from 0.00026 mSv for an operator at a stationary weigh scale to 0.012 mSv for the operator of a portable scale assuming MTO data that suggests that approximately 5% of all trucks are weighed.

Doses calculated for stationary scale operators are assumed to be conservative because of conservative distance assumptions (2 m away from side of truck) and that shielding provided by the structure they are in is not credited. Even with these conservative assumptions, if all 620 UFTP shipments were to be weighed by the same operator, the total received dose would range from 0.005 mSv for an operator at a stationary weigh scale with a large platform to 0.06 mSv for the operator at a weigh scale with a small platform.

Weighings using portable scales are conducted by MTO officers who have stopped a commercial vehicle for potential safety infractions alongside the roadway. As the weight of the UFTP shipments will be very consistent, and MTO will be aware of the UFTP transportation program, the assumption that 31 UFTP shipments will be weighed a given officer is conservative.

6.4 Mechanic – Mobile Repair Service Operator

The potential dose to a mechanic making a minor repair to a UFTP shipment is calculated to be 0.017 mSv. This assumes that the repair required is in very close proximity to the UFTP (0.4 m). While the dose received by the mechanic during the repair is approximately equivalent to two dental x-rays (typically 0.01 mSv per x-ray (Mettler, 2008)), it is highly unlikely that a repair in this location by the same mechanic will be a frequent occurrence. The transport crew will be equipped with dose monitoring equipment and will be trained to instruct the mechanic to minimize exposure by conducting work (when possible) at a greater distance from a loaded package.

7. CONCLUSIONS

Dose rates emitted by a UFTP loaded with 192 bundles of 30 year out-of-reactor CANDU fuel were calculated and presented in NWMO Report TR-2012-06, Generic Transportation Dose Assessment. Using these dose rate data, occupational doses to workers in the proximity of UFTP transport were calculated. Per occurrence dose for activities engaged in by the identified workers was calculated as was the annual dose received by a worker in each category. These results are summarized in Table 15 and Figure 13 below.

In all cases, the maximum individual occupational dose to workers under normal transport conditions was estimated to be below the dose limit for a member of the public (i.e., 1 mSv per year). This assessment concludes that transportation workers would not need to be designated as NEWS.

However, dose rates and resulting occupational doses received by the workers are calculated, and not based on measured values. Dose monitoring of occupational activities will be assessed for drivers and security escorts when the radiation protection plan is developed in support of the operational startup of the used fuel transportation program, including the use of dosimeters worn by the workers.

Driving operations (team driving (straight through) vs. driving with overnight stops) have not been optimized as the eventual repository site destination and associated transport routes are unknown. Driver dose calculations should be re-examined once more route information becomes available.

Table 15: Occupational Dose Summary

Worker	Dose per Occurrence [mSv]	Annual Frequency	Annual Dose [mSv]
Driver			
50 km trip	0.0009	295 shipments	0.27
250 km trip	0.0018	164 shipments	0.30
600 km trip	0.0040	86 shipments	0.34
1200 km trip	0.0077	45 shipments	0.34
1700 km trip	0.0111	32 shipments	0.35
2900 km trip	0.0184	19 shipments	0.35
Commercial Vehicle Inspector			
CVSA Level I	0.0035	31 inspections	0.11
CVSA Level II	0.0017	31 inspections	0.054
CVSA Level VI	0.0052	31 inspections	0.16
Weigh Scale Operator			
Large Stationary Scale	0.0000084	31 weighings	0.00026
Small Scale	0.000089	31 weighings	0.0028
Portable Scale	0.0004	31 weighings	0.012
Mechanic – Mobile Repair Service Operator	0.017	1 repair	0.017

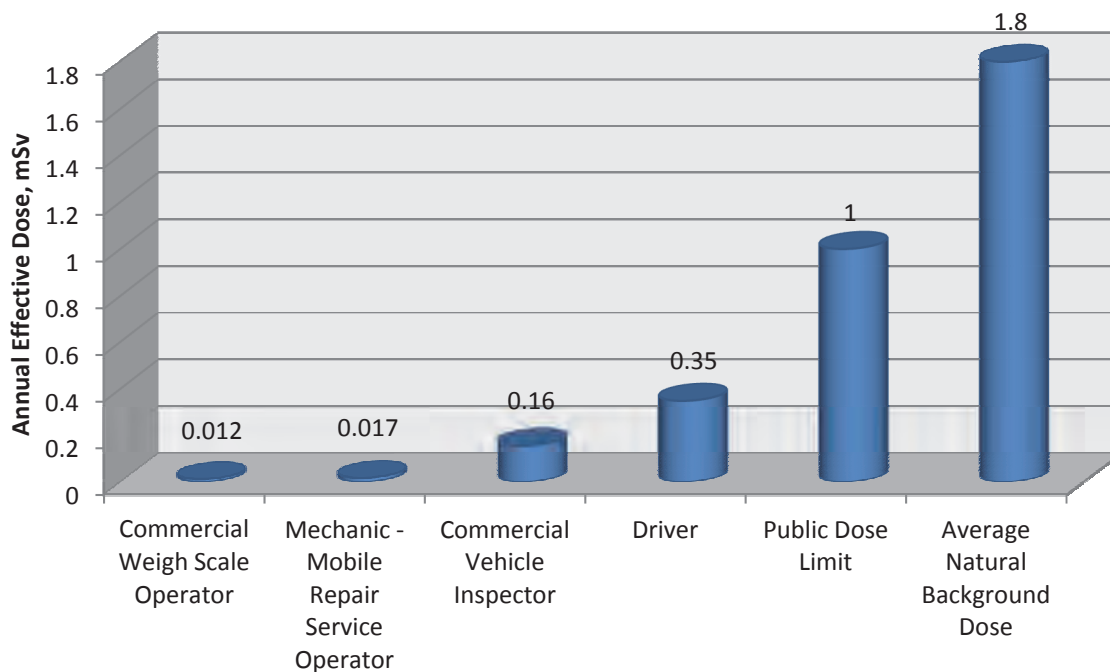


Figure 13: Comparison of Worker Doses

Transportation activities assessed in this report focus on workers involved with a UFTP shipment departing the facility at the point of origin to arriving at the destination facility. Specifically the scope of the assessment covers worker activities from the time a used nuclear fuel shipment is loaded on the trailer, departing from the reactor sites to when the trailer arrives at the APM repository site receiving bay and is disconnected. Activities conducted within the boundaries of the associated facilities to prepare a shipment for transport and process a shipment after arrival are not included in the scope of this report (i.e., loading of fuel into the UFTP, on-site transfers of the UFTP, UFTP inspection and testing, loading, securing of the UFTP onto transport trailer at the point of origin and unloading of UFTP at the destination).

Based on the results presented in this report, the doses calculated for transportation workers are below the dose limit for a member of the public (i.e., 1 mSv per year); and, by extension well below the dose limit of 20 mSv per year for NEWs (i.e., the regulatory dose limit of 100 mSv averaged over five years for a Nuclear Energy Worker).

ACKNOWLEDGEMENTS

The preparation of this report could not have been accomplished without the help of individuals in various organizations. The author would like to thank the following individuals for their input and assistance in the gathering of data and determination of activities and scenarios presented.

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APPENDIX A: RATIONALE FOR LIMITING SCOPE TO WORKERS WITHIN 30 M OF PACKAGE

Assumptions

- Worker is present at 30 m from UFTP every work day for the entire day
- Worker works 8 h per day, 5 days per week, 50 weeks per year = 2000 h/y

Data

• Dose from UFTP at 30 m (220 MWh/kgU)	0.000015 mSv/h	(1)
• Regulatory limit for non-NEW	1 mSv/y	(2)
• Regulatory limit for NEW	100 mSv / 5 y	(2)
	50 mSv/y maximum	
• Annualized dose limit for NEWs ¹	20 mSv/y	

Calculation

$$\begin{aligned}\text{Annual dose to worker at 30 m from UFTP} &= 0.000015 \text{ mSv/h} \times 2000 \text{ h} \\ &= 0.03 \text{ mSv/y}\end{aligned}$$

Comparisons

Dose to worker from UFTP at 30 m is approximately equivalent to:

- 3% of regulatory limit for the general public
- 0.15% of the dose limit for Nuclear Energy Workers

Conclusions

The annual dose to a worker situated 30 m from a UFTP every day for the entire workday is estimated to be 0.03 mSv/y or 3% of the regulatory limit for the general public. Thus the radiological dose due to the transport of used nuclear fuel to workers engaged in activities at distances greater than 30 m from the UFTP is considered negligible. Only activities placing workers at distances within 30 m of the UFTP are included in this assessment.

References

- (1) Batters, S., K. Tsang and U. Stahmer. 2012. Generic Transportation Dose Assessment. Prepared for the NWMO by AMEC NSS Ltd. NWMO Report Number NWMO TR-2012-06. October 2012.
- (2) Canadian Nuclear Safety Commission (CNSC). 2000. Radiation Protection Regulations. SOR/2000-203 plus amendments.

¹ For the purpose of this assessment, doses to workers are compared to an dose limit of 20 mSv/year for NEWs (i.e., the regulatory dose limit of 100 mSv averaged over five years for Nuclear Energy Workers).

APPENDIX B: TRANSPORT ACTIVITIES AND DOSE CALCULATIONS

B.1 TRACTOR-TRAILER HOOKUP / UNHOOK

Performed by: Driver

Requirement: Operational procedures

Description: A UFTP trailer is hooked up to the tractor unit prior to departure or unhooked from the tractor unit after arrival. See Figure B-1 below.

Duration: Hooking up or unhooking the trailer from the tractor typically takes 5 minutes broken down as follows:

- 2 min at 4 m to raise / lower landing gear
- 2 min at 7 m to connect / disconnect electrical and pneumatic hookups
- 1 min at 8 m driving in the cab to connect / disconnect the trailer

Distance: Driver is located 4, 7 and 8 m from the front surface of the UFTP (see Figure B-1).

Frequency: One hookup and one unhook per shipment.

Time references: Ontario Power Generation, Caravan Logistics

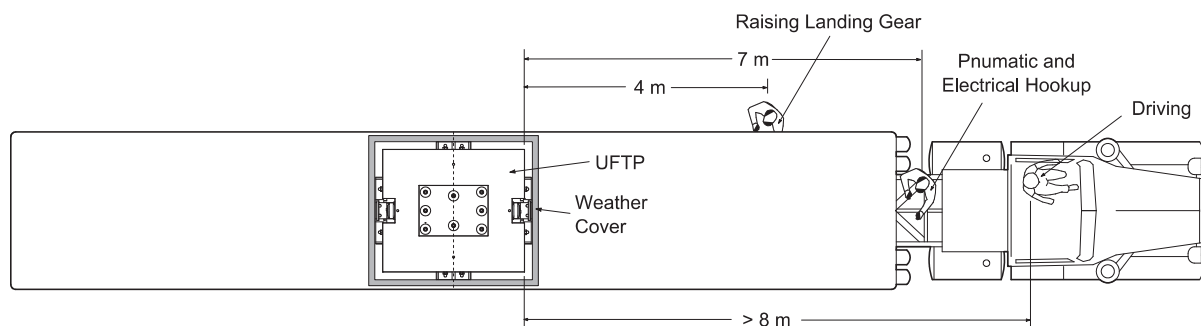


Figure B-1: UFTP Tractor and Trailer being Hooked up or Unhooked

Driver Dose Calculation – Tractor-Trailer Hookup / Unhook

The driver will receive dose from the shipment during tractor-trailer connect/disconnect operations. Shielding provided by the vehicle is not credited.

Dose received during raising and lowering of landing gear

Dose rate at 4 m = 0.0008 mSv/h (see Figure 4 in main report)

$$\begin{aligned}\text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0008 \text{ mSv/h} \times (2 \text{ min}) \\ &= 2.7 \times 10^{-5} \text{ mSv}\end{aligned}$$

Dose received during connection / disconnection of electrical and pneumatic lines

Dose rate at 7 m = 0.00025 mSv/h (see Figure 4 in main report)

$$\begin{aligned}\text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00025 \text{ mSv/h} \times (2 \text{ min}) \\ &= 8.3 \times 10^{-6} \text{ mSv}\end{aligned}$$

Dose received during connection / disconnection of tractor

Dose rate at 8 m = 0.00020 mSv/h (see Figure 4 in main report)

$$\begin{aligned}\text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00020 \text{ mSv/h} \times (1 \text{ min}) \\ &= 3.3 \times 10^{-6} \text{ mSv}\end{aligned}$$

Total dose received during hookup / unhook

$$\begin{aligned}\text{Total Dose} &= \text{Dose at 4 m} + \text{Dose at 7 m} + \text{Dose at 8 m} \\ &= 2.7 \times 10^{-5} \text{ mSv} + 8.3 \times 10^{-6} \text{ mSv} + 3.3 \times 10^{-6} \text{ mSv} \\ &= 3.8 \times 10^{-5} \text{ mSv}\end{aligned}$$

The dose received by the driver during a tractor-trailer hookup or unhook operation is 3.8×10^{-5} mSv.

B.2 DOCUMENTATION CHECK

Performed by: Driver

Requirement: In accordance with CNSC Regulatory Guide G-208 – Transportation Security Plans for Category I, II or III Nuclear Material.

Description: Driver is in tractor cab reviewing shipment documentation, bills of lading and manifests. See Figure B-2 below.

Duration: Typically 15 minutes.

Distance: Driver is located in the cab of the tractor approximately 8 m in front of the UFTP as shown in Figure B-2. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: Each shipment - prior to departure and upon arrival at destination

Time, distance and frequency references: Ontario Power Generation, Caravan Logistics.

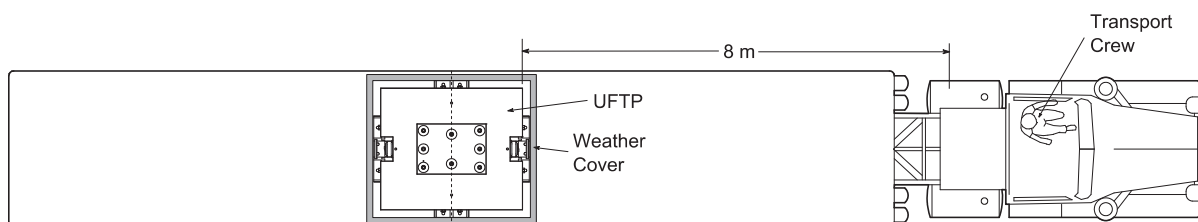


Figure B-2: Documentation Check prior to and post Shipment

Driver Dose Calculation – Documentation Check

The driver may receive dose from the shipment during documentation check operations. Shielding provided by the vehicle is not credited.

Note, conservatively, this operation is assumed to take place in the tractor cab. However, it can take place at a location at a greater distance

Dose received during documentation check

Dose rate at 8 m = 0.00020 mSv/h (see Figure 4 in main report)

Dose = dose rate x duration

= 0.00020 mSv/h x (15 min)

= 5.0×10^{-5} mSv

The dose received by the driver during a document check is 5.0×10^{-5} mSv.

B.3 REST / RELIEF STOP

Performed by: Transport Crew (Driver and Security Escort)

Requirement: In accordance with CNSC Regulatory Guide G-208 – Transportation Security Plans for Category I, II or III Nuclear Material, once loaded and in transit, the vehicle should never be left unattended.

Description: One crew member is attending to vehicle while other crew member goes for rest / food / relief. See Figure B-3 below.

Duration: Typically 30 minutes.

Distance: The transport crew is located in the cab of the tractor approximately 8 m in front of the UFTP as shown in Figure B-3. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: One stop for every 400 km travelled. All trips over 200 km in length are assumed to have at least one stop.

Time, distance and frequency references: Ontario Power Generation, Caravan Logistics.

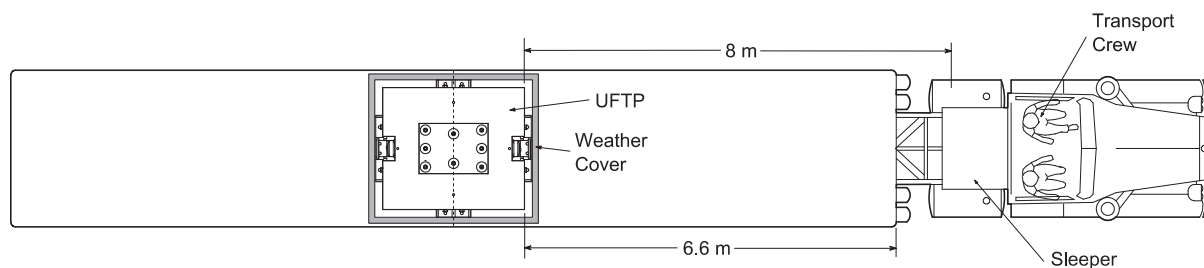


Figure B-3: UFTP Shipment during Transport

Driver Dose Calculation – Rest / Relief Stop

The driver will receive dose from the shipment during a rest stop. Shielding provided by the vehicle is not credited.

Dose received during rest stop

$$\begin{aligned}\text{Dose rate at 8 m} &= 0.00020 \text{ mSv/h (see Figure 4 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00020 \text{ mSv/h} \times (0.5 \text{ h}) \\ &= 1.0 \times 10^{-4} \text{ mSv}\end{aligned}$$

The dose received by the driver during a rest stop is 1.0×10^{-4} mSv.

B.4 REFUELLING – UFTP TRACTOR-TRAILER

- Performed by: Driver / Security Escort in Cab / Commercial Driver at adjacent pump
- Requirement: Only trips of 1400 km or more require refuelling with loaded UFTP
- Description: Driver stands beside vehicle during refuelling. Security escort remains in tractor cab. Commercial driver refuels commercial vehicle at adjacent pump. See Figure B-4 below.
- Duration: One vehicle refuelling stop is typically 20 minutes in length.
- Distance: Driver is located 6 m from the UFTP. Security Escort is located 8 m from the UFTP. Commercial driver is located at 3 m from the UFTP (see Figure B-4).
- Frequency: Frequency is calculated based on trip length. See Calculations in Appendix B-5. Presence of a given commercial driver at a refuelling stop is assumed to be a singular event.
- Time, distance and frequency references: Caravan Logistics, Ontario Power Generation

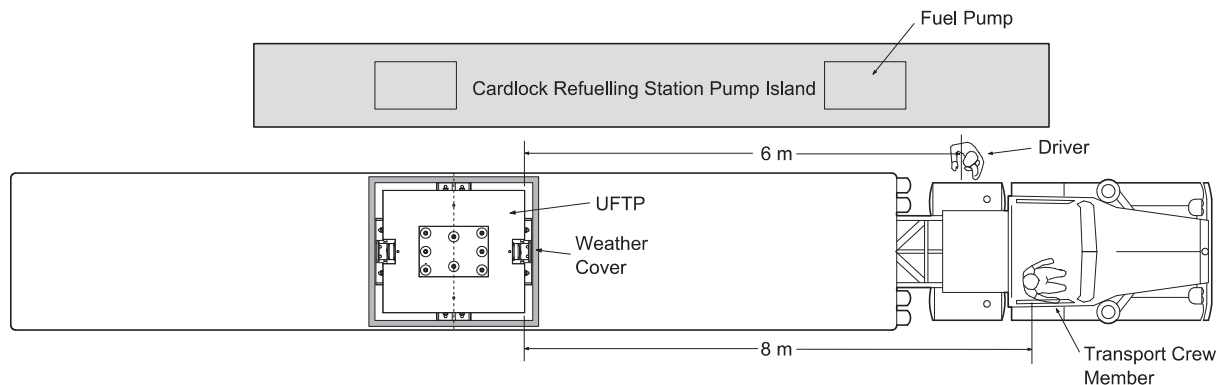


Figure B-4: UFTP Shipment in Cardlock Refuelling Station

Driver Dose Calculation - Refuelling

The driver will receive dose from the shipment during refuelling of the UFTP tractor-trailer. Shielding provided by the vehicle is not credited.

Dose received during refuelling

$$\begin{aligned}\text{Dose rate at 6 m} &= 0.00035 \text{ mSv/h (see Figure 4 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00035 \text{ mSv/h} \times (0.33 \text{ h}) \\ &= 1.2 \times 10^{-4} \text{ mSv}\end{aligned}$$

The dose received by the driver during refueling is 1.2×10^{-4} mSv.

B.5 EN-ROUTE TRANSPORT AND DRIVER DOSE CALCULATION

Performed by: Transport Crew (Driver and Security Escort)

Requirement: In accordance with Ontario Regulation 555/06, Hours of Service.

Description: Crew is in UFTP tractor cab driving en-route to repository. See Figure B-5 below.

Duration: In transit time is dependent on trip length. Transit times for various trip lengths are calculated in Table 6 of main report.

Distance: The transport crew is located in the cab of the tractor approximately 8 m in front of the UFTP as shown in Figure B-5. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: Frequency is calculated based on trip length. See calculations in Table 9 of main report

Time, distance and frequency references: See calculations in Tables 6 and 9 of main body.

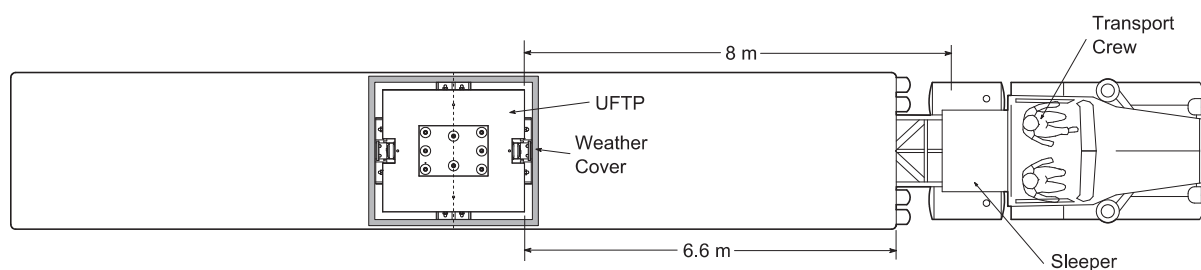


Figure B-5: UFTP Shipment during Transport

Driver Dose Calculation

The driver will receive a radiological dose from the shipment during various transportation activities. The dose received during transport is the sum of all the doses received during each activity.

Dose received during transport

The doses received by the driver during pre- and post-shipment activities and while en-route are tabulated in Table B-5-1. Additional shielding provided by trailer deck is not credited in the calculations.

Annual dose received by driver

The estimated annual doses received by a driver are presented in Table B-5-2.

Conclusions

The annual dose to a driver or transport crew member ranges between 0.27 mSv per year and 0.35 mSv per year, which is less than the regulatory public dose limit.

Table B-5-1: Driver Dose Summary – Per-Shipment Dose

Doses in mSv	Shipment Length					
	50 km	250 km	600 km	1200 km	1700 km	2900 km
Pre-shipment Activities						
Trailer Hookup	0.000038	0.000038	0.000038	0.000038	0.000038	0.000038
Documentation Check	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050
Condition Inspection	0.00058	0.00058	0.00058	0.00058	0.00058	0.00058
Pre-shipment Total	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066
En-route Activities						
Driving (time: hh:mm)	0.00015 (0:44)	0.00095 (4:45)	0.0020 (9:51)	0.0037 (18:38)	0.0052 (26:00)	0.0087 (43:30)
Rest Stops (frequency)	0.00 (0)	0.00010 (1)	0.00010 (1)	0.00030 (3)	0.00040 (4)	0.00070 (7)
Condition Inspections (frequency)	0.00 (0)	0.00 (0)	0.0012 (2)	0.0029 (5)	0.0046 (8)	0.0081 (14)
Refuelling (frequency)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00012 (1)	0.00023 (2)
Post-shipment Activities						
Trailer Unhook	0.000038	0.000038	0.000038	0.000038	0.000038	0.000038
Documentation Check	0.000050	0.000050	0.000050	0.000050	0.000050	0.000050
Post-Shipment Total	0.000088	0.000088	0.000088	0.000088	0.000088	0.000088
Per-Shipment Dose	0.0009	0.0018	0.0040	0.0077	0.011	0.018

Table B-5-2: Driver Dose Summary – Annual Dose

Doses in mSv	Shipment Length					
	50 km	250 km	600 km	1200 km	1700 km	2900 km
Annual Shipments	295	164	86	45	32	19
Pre-shipment Activities						
Trailer Hookup	0.011	0.006	0.003	0.002	0.001	0.001
Documentation Check	0.015	0.008	0.004	0.002	0.002	0.001
Condition Inspection	0.17	0.094	0.050	0.026	0.018	0.011
Pre-shipment Total	0.20	0.11	0.057	0.030	0.021	0.013
En-route Activities						
Driving	0.044	0.16	0.17	0.17	0.17	0.17
Rest Stops	0.00	0.016	0.009	0.014	0.013	0.013
Condition Inspections	0.00	0.00	0.099	0.13	0.15	0.15
Refuelling	0.00	0.00	0.00	0.00	0.004	0.004
En-route Total	0.044	0.17	0.277	0.31	0.33	0.34
Post-shipment Activities						
Trailer Unhook	0.011	0.006	0.003	0.002	0.001	0.001
Documentation Check	0.015	0.008	0.004	0.002	0.002	0.001
Post-shipment Total	0.026	0.014	0.008	0.004	0.003	0.002
Annual Driver Dose	0.27	0.30	0.34	0.34	0.35	0.35

B.6 VEHICLE INSPECTIONS

Performed by: Vehicle Inspector / Driver

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 216.1, a commercial vehicle may be stopped, and the vehicle, equipment and contents may be examined.
Additionally, in accordance with O. Reg. 199/07, s. 8 (1), a driver shall monitor the condition of each commercial motor vehicle and trailer he or she is driving, drawing or in charge of to detect the presence of a major or minor defect.

Description: The UFTP tractor-trailer is inspected by an inspector to the requirements of the Commercial Vehicle Safety Alliance (CVSA) Level I, Level II or Level VI inspections or by the driver to the requirements of an en-route vehicle condition inspection. Figure B-6-1 below shows the elements of a systematic circle check of the vehicle which provides the basis for all inspections.

Duration: Time required to inspect the vehicle is dependent on the inspection level.

- Level I Inspection: 1 hour
- Level II Inspection: ½ hour
- Level VI Inspection: 1½ hours
- Condition Inspection: 10 minutes

Distance: Inspector or driver is located less than 1 m from side of the truck while performing the circle check. Level I and Level VI inspections also require inspector to inspect the underside of the vehicle.

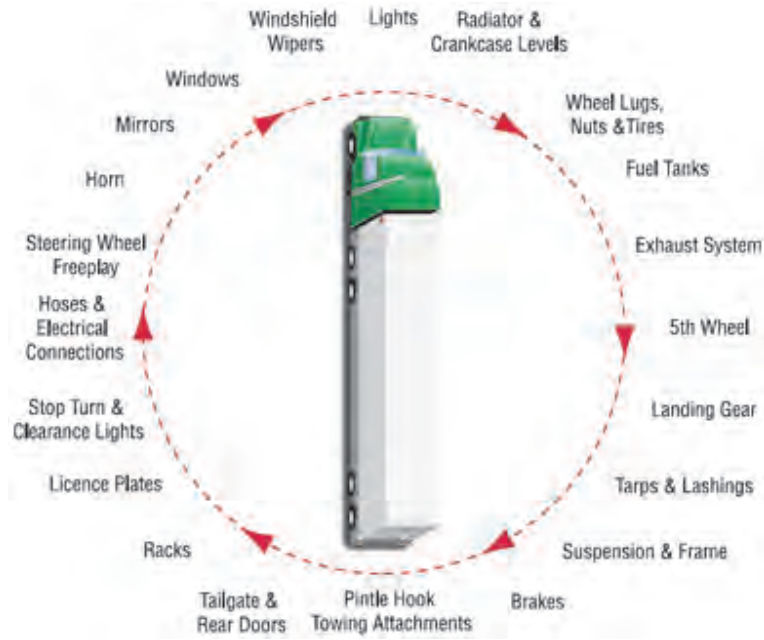
For dose calculations, the circle check around the vehicle is divided into 46 areas within 12 zones (numbered 0 through 11). Each area is 1 m wide and extends outward 1 m from the vehicle. The areas and zones are illustrated in Figure B-6-2. Inspection time is assumed to be distributed equally between the 46 areas. The distance between the UFTP and the area is approximated by the number of the zone (i.e.: an inspector in an area in Zone 2 is located approximately 2 m from the UFTP).

Frequency: CVSA inspection frequency for a given vehicle is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and inspected by the same inspector.

En-route vehicle condition inspections are conducted by the driver prior to departure and once for approximately every 200 km traveled. En-route vehicle condition inspections are not required for trips under 300 km in length.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO),
Ontario Power Generation (OPG),
Caravan Logistics
Commercial Vehicle Safety Alliance



Source: Ontario Ministry of Transportation (MTO)

Figure B-6-1: Commercial Vehicle Circle Check

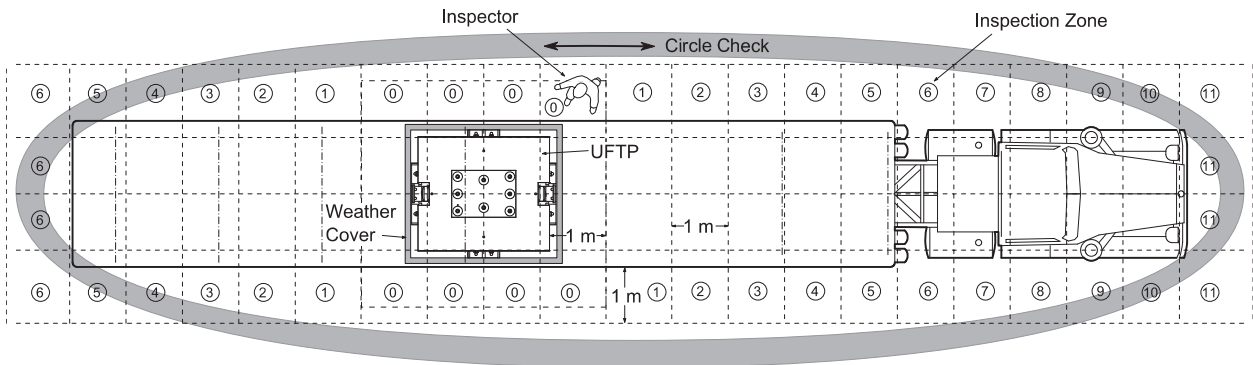


Figure B-6-2: UFTP Vehicle Inspection Areas and Zones

Inspection Dose Calculation

The inspector or driver will receive a radiological dose from the shipment during the inspection. The dose received during the inspection is the sum of the doses received in each zone.

Dose received during Inspection

The doses received by the inspector or driver during a CVSA Level I, II and VI inspection and vehicle condition assessment by the driver are tabulated in Table B-6-2. Additional shielding provided by trailer deck is not credited in the calculations.

The dose of 0.0045 mSv in one hour represents an average distance of 1.2 m from the UFTP during the entire inspection.

Annual dose received by Inspector

Assuming that the inspector inspects 5% of all UFTP shipments (31 shipments) per year, the estimated annual doses received by an inspector are presented in Table B-6-1.

Table B-6-1: Dose Received during Inspection

Inspection Type	Dose per Inspection [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]
CVSA Level I	0.0035	31	0.11
CVSA Level II	0.0017	31	0.054
CVSA Level VI	0.0052	31	0.16

Note: Figures rounded to 2 significant digits. Annual dose may not be exact product due to round-off.

Annual dose received by Driver

The vehicle condition assessment is one of numerous activities performed by the driver. Annual dose received by the driver is presented in Appendix B-5

Conclusions:

The annual dose to an inspector carrying out 31 CVSA Level VI inspections of a UFTP shipment is estimated to be 0.16 mSv, which is less than the regulatory public dose limit.

Table B-6-2: Dose Received during Inspection

Zone	Average Distance from UFTP	Dose rate [mSv/h] ¹	Frequency in Zone during Circle Check	Condition Assessment		CVSA Level I		CVSA Level II		CVSA Level VI	
				Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]
0	0.4 m	0.014	8	01:44	4.0×10^{-4}	10:26	2.4×10^{-3}	05:13	1.2×10^{-3}	15:39	3.6×10^{-3}
1	1 m	0.0060	4	00:52	8.6×10^{-5}	05:13	5.2×10^{-4}	02:37	2.6×10^{-4}	07:50	7.8×10^{-4}
2	2 m	0.0024	4	00:52	3.5×10^{-5}	05:13	2.1×10^{-4}	02:37	1.1×10^{-4}	07:50	3.2×10^{-4}
3	3 m	0.0012	4	00:52	1.7×10^{-5}	05:13	1.0×10^{-4}	02:37	5.2×10^{-5}	07:50	1.6×10^{-4}
4	4 m	0.00080	4	00:52	1.2×10^{-5}	05:13	7.0×10^{-5}	02:37	3.5×10^{-5}	07:50	1.0×10^{-4}
5	5 m	0.00052	4	00:52	7.5×10^{-6}	05:13	4.5×10^{-5}	02:37	2.3×10^{-5}	07:50	6.8×10^{-5}
6	6 m	0.00035	6	01:18	7.6×10^{-6}	07:50	4.6×10^{-5}	03:55	2.3×10^{-5}	11:44	6.8×10^{-5}
7	7 m	0.00025	2	00:26	1.8×10^{-6}	02:37	1.1×10^{-5}	01:18	5.4×10^{-6}	03:55	1.6×10^{-5}
8	8 m	0.00020	2	00:26	1.4×10^{-6}	02:37	8.7×10^{-6}	01:18	4.3×10^{-6}	03:55	1.3×10^{-5}
9	9 m	0.00016	2	00:26	1.2×10^{-6}	02:37	7.0×10^{-6}	01:18	3.5×10^{-6}	03:55	1.0×10^{-5}
10	10 m	0.00013	2	00:26	9.8×10^{-7}	02:37	5.9×10^{-6}	01:18	2.9×10^{-6}	03:55	8.8×10^{-6}
11	11 m	0.00012	4	00:52	1.7×10^{-6}	05:13	1.0×10^{-5}	02:37	5.2×10^{-6}	07:50	1.6×10^{-5}
Totals			46	10:00	0.00058	60:00	0.0035	30:00	0.0017	90:00	0.0052

1 – See Figure 4 in main report.

Note: Figures rounded to 2 significant digits. Sums of columns may differ from totals due to round-off.

B.7 WEIGHING AT WEIGH STATION

Performed by: Weigh Scale Operator

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 124, a vehicle may be stopped, weighed and examined.

Description: A UFTP shipment is weighed at a stationary weigh scale. See Figure B-6 below.

Duration: One vehicle weighing stop is typically 2 minutes in length (0.033 h).

For dose calculations, the dose received by the weigh scale operator is assumed to be the sum of the dose received during the 2 minute weighing and the dose received as the UFTP tractor trailer exits the inspection station. While exiting the weigh scale, a vehicle speed of 5 km per hour is assumed.

Distance: Weigh scale operator is located 2 m from the cab of the tractor-trailer unit. This equates to approximately 9 m from the front surface of the UFTP (see Figure B-7-1) during the weighing and 2 m from the UFTP as the tractor trailer exits the weigh station.

For weigh scales with small weigh platforms, front and rear axle groupings are weighed independently. Weigh scale operator may be within 2 m of the UFTP during weighing of rear axle grouping. See Figure B-7-2.

Frequency: Frequency of weighing at weigh station is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year. The number of commercial vehicles weighed is significantly higher.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and weighed at a weigh station by the same weigh scale operator.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO)

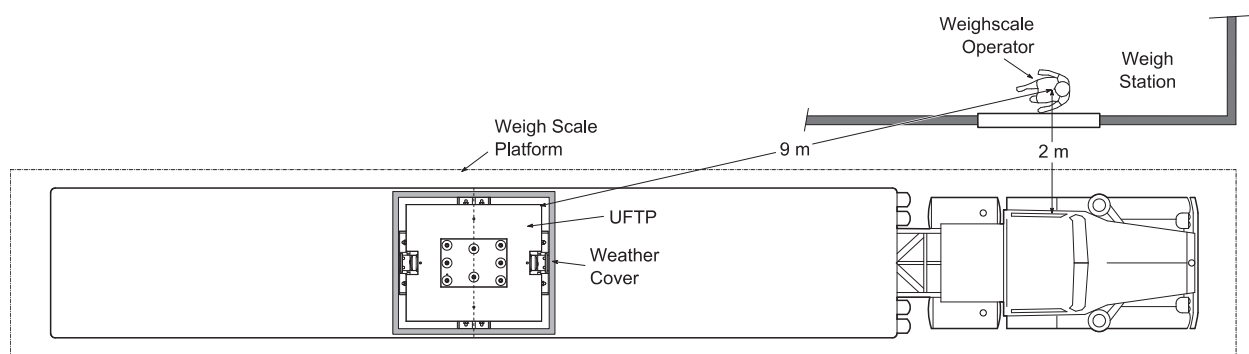


Figure B-7-1: UFTP Shipment in Stationary Weigh Scale (Large Platform)

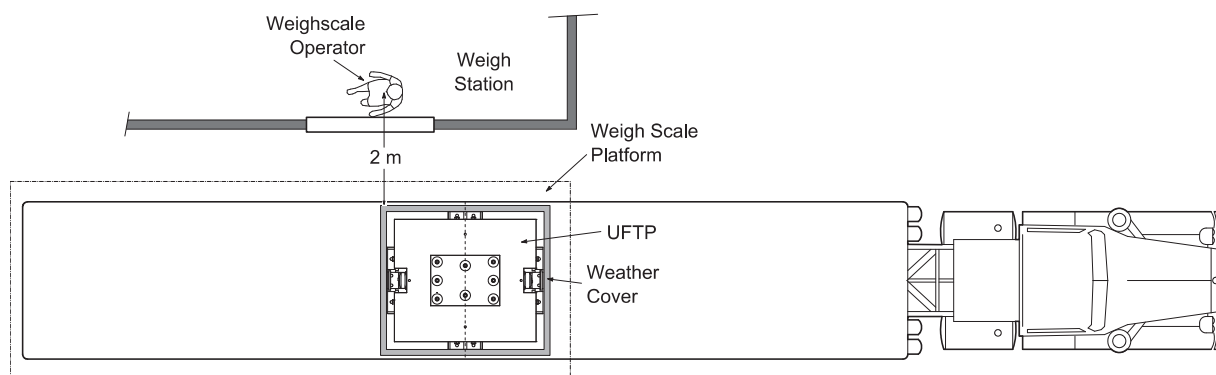


Figure B-7-2: UFTP Shipment in Stationary Weigh Scale (Small Platform)

(Weighing of Rear Axle Group)

Weigh Scale Operator Dose Calculation

The weigh scale operator will receive dose from the shipment during the weighing and from the slow moving shipment as the shipment exits the scale. The dose received by the weigh scale operator is the sum of these two doses. Shielding provided by the building is not credited.

Dose received during weighing (large platform and front axle group of small platform)

$$\begin{aligned}\text{Dose rate at 9 m} &= 0.00016 \text{ mSv/h (see Figure B-7-1)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00016 \text{ mSv/h} \times 0.033 \text{ h} \\ &= 5.33 \times 10^{-6} \text{ mSv}\end{aligned}$$

Dose received during weighing (small platform rear axle group)

$$\begin{aligned}\text{Dose rate at 2 m} &= 0.00242 \text{ mSv/h (see Figure B-7-2)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00242 \text{ mSv/h} \times 0.033 \text{ h} \\ &= 8.07 \times 10^{-5} \text{ mSv}\end{aligned}$$

Dose received from passing slow-moving UFTP shipment

Dose received by a stationary receptor from moving source is presented in Appendix C. Using the method described, the dose received by the weigh scale operator at 2 m from side of truck as it passes at 5 km/h is 3.04×10^{-6} mSv.

Total dose received by weigh scale operator during weighing (large platform)

$$\begin{aligned}\text{Total Dose} &= \text{dose during weighing} + \text{dose due to drive-by} \\ &= 5.33 \times 10^{-6} \text{ mSv} + 3.04 \times 10^{-6} \text{ mSv} \\ &= 8.4 \times 10^{-6} \text{ mSv}\end{aligned}$$

The dose received by the weigh scale operator during the weighing is 8.4×10^{-6} mSv.

Total dose received by weigh scale operator during weighing (small platform)

$$\begin{aligned}\text{Total Dose} &= \text{dose during weighing front axle group} + \text{rear axle group} \\ &\quad + \text{dose due to drive-by} \\ &= 5.33 \times 10^{-6} \text{ mSv} + 8.07 \times 10^{-5} \text{ mSv} + 3.0 \times 10^{-6} \text{ mSv} \\ &= 8.9 \times 10^{-5} \text{ mSv}\end{aligned}$$

The dose received by the weigh scale operator during the weighing is 8.9×10^{-5} mSv.

Annual dose received by weigh scale operator

Assume 5% of shipments (31 shipments) are weighed at stationary weigh scales per year by the same weigh scale operator:

Large platform

$$\begin{aligned}\text{Dose} &= 8.4 \times 10^{-6} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.00026 \text{ mSv (0.026 \% of regulatory dose limit)}\end{aligned}$$

The annual dose received by a large platform weigh scale operator is 0.00026 mSv.

If all 620 shipments are weighed by same operator, the annual dose is 0.0052 mSv.

Small platform

$$\begin{aligned}\text{Dose} &= 8.9 \times 10^{-5} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.0028 \text{ mSv (0.28 \% of regulatory dose limit)}\end{aligned}$$

The annual dose received by a small platform weigh scale operator is 0.0028 mSv.

If all 620 shipments are weighed by same operator, the annual dose is 0.055 mSv.

Conclusions

The radiological dose due to used fuel transportation estimated to be received by a weigh scale operator is 0.00026 mSv, which is less than the regulatory dose limit for the public.

B.8 WEIGHING WITH PORTABLE SCALE

Performed by: Portable Weigh Scale Operator

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 124, a vehicle may be stopped, weighed and examined.

Description: UFTP tractor-trailer is weighed using a portable weigh scale. See Figure B-8 below.

Duration: Time required to weigh tractor-trailer is typically 15 minutes (0.25 h).

Distance: Weigh scale operator is located less than 1 m from side of the tractor-trailer. Weigh scale operator places scales in front of each of the 7 axles one axle at a time and tractor-trailer moves forward onto scales for weighing. Relative distances between the operator position at each axle and the surface of the UFTP are shown in Figure B-8. Time required to weigh each axle is assumed to be the same.

Frequency: Frequency of weighing with portable scales is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year. The number of commercial vehicles weighed at government and commercial weigh stations is significantly higher.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and weighed with a portable weigh scale by the same weigh scale operator.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO)

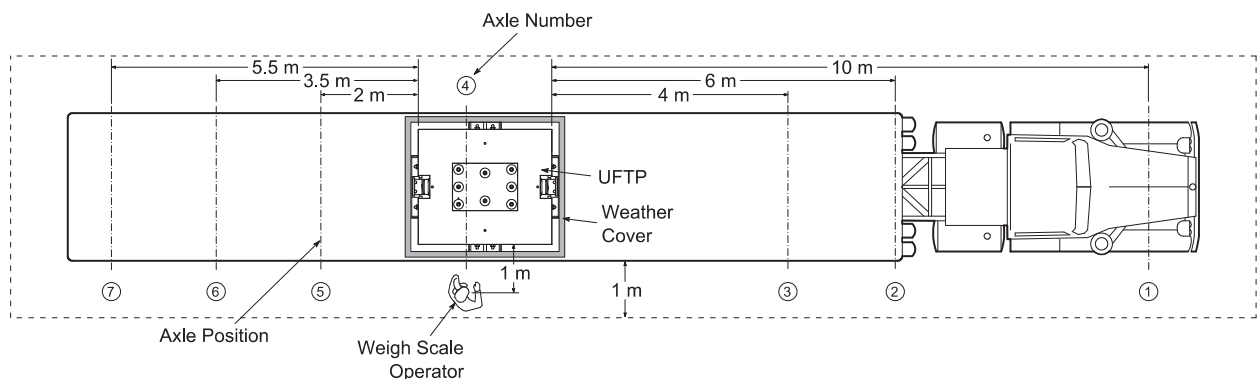


Figure B-8: UFTP Shipment weighed with Portable Weigh Scale

Portable Weigh Scale Operator Dose Calculation

The portable weigh scale operator will receive dose from the shipment during the weighing of each axle. The dose received by the portable weigh scale operator is the sum of the doses received at each axle.

Dose received during Weighing

The dose to the portable weigh scale operator is calculated in Table B-8. Additional shielding provided by trailer deck is not credited.

Table B-8: Dose Received during Weighing with Portable Scale

Axle	Distance from UFTP [m]	Dose rate [mSv/h] ¹	Time [min]	Dose [mSv]
1	10	0.00013	2:09	0.000005
2	6	0.00035	2:09	0.000013
3	4	0.0008	2:09	0.000029
4	1	0.0060	2:09	0.00022
5	2	0.0024	2:09	0.000086
6	3.5	0.0010	2:09	0.000036
7	5.5	0.00042	2:09	0.000015
Totals			15	0.00040

1 – See Figure 4 in main report.

A dose of 0.00040 mSv for one weighing is equivalent to 0.0016 mSv in one hour which represents an average distance of 2.5 m (see Figure 4 in main report) from the UFTP during the entire weighing.

Annual dose received by weigh scale operator

Assume operator weighs 5% of shipments (31 shipments) per year:

$$\begin{aligned}\text{Dose} &= 4.0 \times 10^{-4} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.012 \text{ mSv (1.2\% of public dose limit)}\end{aligned}$$

The annual dose received by a portable weigh scale operator is 0.012 mSv.

If all 620 shipments are weighed by same operator, the annual dose is 0.25 mSv.

Conclusions:

The annual dose due to the weighing of the UFTP shipment estimated to be received by a portable weigh scale operator is 0.012 mSv, which is less than the regulatory public dose limit.

B.9 MINOR BREAKDOWN OR TIRE REPAIR

Performed by: Mechanic / Tow Truck Operator

Requirement: ALARA

Description: A malfunction or broken part on the UFTP tractor-trailer is repaired en-route. See Figure B-9 below.

Duration: Changing the inner tire of a dual tire pair typically requires 1 hour. Repair of a maxi-pot brake chamber typically requires ½ hour.

Distance: Mechanic is located 0.4 m from the UFTP (see Figure B-9) for the tire repair and at 1 m for the maxi-pot repair.

Frequency: Singular event.

Time, distance and frequency references: Caravan, Marvin Freiburger and Sons.

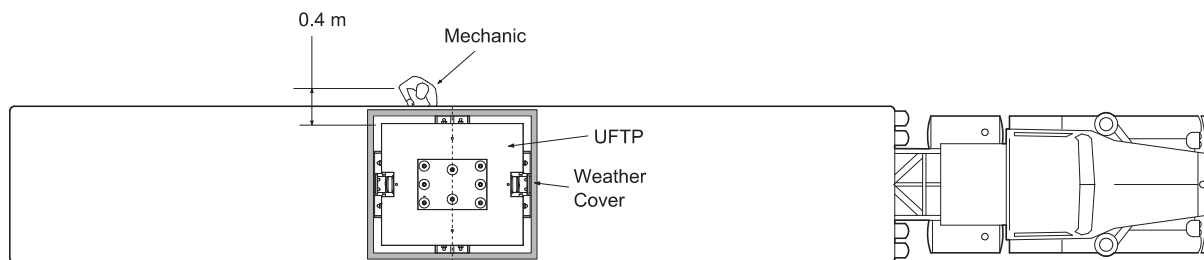


Figure B-9: Performing Minor Repair on UFTP Shipment

Mechanic Dose Calculation

A mechanic or tow truck driver may receive dose from the shipment during a minor repair or while fixing a tire. A tire or minor breakdown repair is assumed to be a singular occurrence experienced by a given mechanic. Conservatively, dose rates for peak burnup fuel (see Section 3.2.1) are used in the dose calculations.

Dose received during Tire Repair

$$\begin{aligned}\text{Dose rate at 0.4 m} &= 0.017 \text{ mSv/h (see NWMO TR-2012-06, Table A-3-1b)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.017 \text{ mSv/h} \times 1 \text{ h} \\ &= 0.017 \text{ mSv}\end{aligned}$$

Dose received during Breakdown Repair

$$\begin{aligned}\text{Dose rate at 1 m} &= 0.0082 \text{ mSv/h (see NWMO TR-2012-06, Table A-3-1b)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0082 \text{ mSv/h} \times 1/2 \text{ h} \\ &= 0.0041 \text{ mSv}\end{aligned}$$

Conclusions:

The radiological dose due to used fuel transportation estimated to be received by a mechanic or tow truck operator is 0.017 mSv, which is less than the regulatory dose limit for the public.

APPENDIX C: CALCULATION OF DOSE TO INDIVIDUAL DUE TO PASSING UFTP SHIPMENT

Several scenarios identified in this report include a stationary worker exposed to a UFTP shipment as it slowly passes by (i.e., a weigh scale operator). A radiological dose from the shipment is received by the worker during this exposure. This appendix describes the method used to account for the dose received due to the passing shipment.

This appendix provides an estimated exposure of a person standing at a fixed distance (l) normal to the transport-truck path going at a constant speed (v). The assumptions used in deriving the exposure are listed as follows.

1. The UFTP shipment will not change its travelling speed.
2. The person is stationary and facing perpendicular to the UFTP shipment travel path during the exposure period.
3. The person is located sufficiently far away from the UFTP therefore a point-source approximation can be applied, i.e. using the $1/r^2$ approximation to estimate dose rates at distance farther than 5 m.
4. The person is on the same elevation as the UFTP; no credit is given to the risen height of the truck bed.
5. No credit is given to any intervening structure between the person and the UFTP shipment; therefore there is no material attenuation other than geometric attenuation.

C.1 INTEGRATED DOSE AT THE RECEPTOR

Assuming the person standing at P is at a fixed normal distance l from the travel path of the transport truck (see Figure C-1), the dose rate at location P, defined as $d(P)$, is inversely proportional to the distance between the UFTP and the receptor, i.e. distance r .

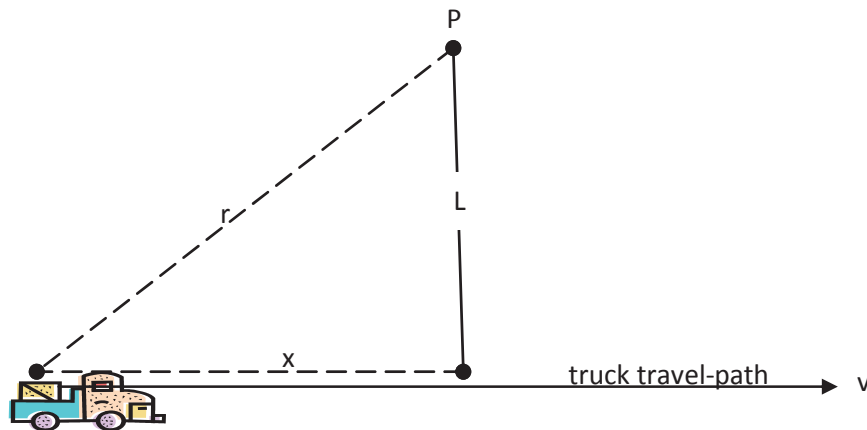


Figure C-1: Schematic of the Receptor Location P to the Travel Path

If S is defined to be the end-on dose rate at h metres from the UFTP, then $d(r)$ at distance r can be formulated as follows.

$$d(r) = \frac{S \times h^2}{r^2} \quad (C1)$$

or

$$d(r) = \frac{S \times h^2}{(x^2 + l^2)} \quad (C2)$$

where x is the distance of the UFTP to the plane that is perpendicular to travel-path. Distance x at time t for a truck travelling at constant speed v is defined as

$$x = vt \quad (C3)$$

Therefore the total dose D at the receptor location P due to an approaching transport truck carrying 1 UFTP can be calculated by integrating equation C2.

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{(vt)^2 + l^2} dt \quad (C4)$$

Since:

$$dx = vdt \quad (C5)$$

equation C4 becomes:

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{x^2 + l^2} \frac{dx}{v} \quad (C6)$$

Completing the integration, the total dose D for a person standing at location P due to a non-stopping transport truck carrying one UFTP travelling at constant speed v at a non-varying distance L normal to the travel path is calculated by the following equation.

$$D = \frac{\pi S h^2}{3600vl} \quad (C 7)$$

The units for v and l are in m/s and m respectively. The units for D and S are in mSv and mSv/h respectively.

C.1 DOSE RATE PROFILE AT THE RECEPTOR

Presenting the information in a different format, Table C-1 shows the variation of the dose exposure as a function of truck speed and the separation distance l . Note that all doses are calculated with no credit given to any intervening structures between the receptor and the truck.

Table C-1: Integrated Dose at different Truck Speeds and Separating Distances

Distance l from Receptor to Truck Path, m	Integrated Dose D at Receptor Location P, mSv						
	5 km/h	10 km/h	24 km/h	30 km/h	50 km/h	80 km/h	100 km/h
2 m	3.0E-06	1.5E-06	6.4E-07	5.1E-07	3.0E-07	1.9E-07	1.5E-07
3 m	2.0E-06	1.0E-06	4.2E-07	3.4E-07	2.0E-07	1.3E-07	1.0E-07
10 m	7.0E-07	3.5E-07	1.5E-07	1.2E-07	7.0E-08	4.4E-08	3.5E-08
30 m	2.5E-07	1.2E-07	5.1E-08	4.1E-08	2.5E-08	1.5E-08	1.2E-08

APPENDIX D: RATIONALE FOR LIMITING SCOPE TO ROAD TRANSPORT

Assumptions

- Radiological dose due to road transport bounds occupational dose received from road and rail modes of transport

Data

Transport Driver

- Tractor-trailer driver receives highest occupational dose due to road transport
- From Appendix B-5 (highest dose to driver – 0.35 mSv for a 2900 km trip):
 - o Annual dose due to driving 0.17 mSv
 - o Annual dose due to inspections 0.15 mSv
 - o Annual dose due to other activities 0.03 mSv

Assessment

Dose Estimate for Locomotive Engineer:

- Locomotive engineer is responsible for the safe operation of the train from point of origin to destination.
- Train consists of a minimum of five railcars each containing 2 UFTPs, with buffer cars on each end and two locomotives pulling the train (1)
- Only dose rate emitted by from first UFTP on rail car need be considered. Radiation from the UFTPs behind the first must pass through its own shielding plus the shielding and contents of all UFTPs in front of it. It has been shown (2) that radiation from UFTPs behind the first is negligible at the front external face of the first UFTP.
- A typical railcar is assumed to be 15 m long. A typical locomotive (EMD SD40) is assumed to be 21 m long. Together, the buffer car and 2nd locomotive would be at least 36 m long.
- The locomotive engineer would be located at least the length of the buffer car and the rear locomotive away from the first UFTP. As this distance is greater than 30 m, (without crediting shielding provided locomotive) the dose to the locomotive engineer during transit would be negligible (see Appendix A).
- As dose due to driving accounts for approximately 50% of a drivers occupational dose and a locomotive engineer would receive negligible dose during this time, it can be concluded that a truck driver will receive a higher occupational dose than a locomotive engineer.

Dose Estimate for Intermodal Transfer Worker:

- Intermodal transfer worker is responsible for loading or unloading UFTP onto or from a railcar.
- Loading and unloading will typically take place at a specialized designated facility.
- Only dose rate emitted by from one UFTP on railcar need be considered. Radiation from the UFTPs behind the first must pass through its own shielding plus the shielding and contents of all UFTPs in front of it. It has been shown (2) that radiation from UFTPs behind the first is negligible at the front external face of the first UFTP.
- Most of the loading and unloading operations are anticipated to be automated.
- Transfer is assumed to take 5 minutes during which the worker is assumed to be located an average distance of 2 m from the UFTP for 4 minutes and right beside the UFTP for 1 minute.
- Dose received

Dose received at 2 m from UFTP

Dose rate at 2 m = 0.0024 mSv/h (see Figure 4 in main report)

$$\begin{aligned}\text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0025 \text{ mSv/h} \times 0.0667 \text{ h} \\ &= 1.62 \times 10^{-4} \text{ mSv}\end{aligned}$$

Dose received at contact with UFTP

Dose rate at contact = 0.0139 mSv/h (see Figure B-7-2)

$$\begin{aligned}\text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0139 \text{ mSv/h} \times 0.0167 \text{ h} \\ &= 2.32 \times 10^{-4} \text{ mSv}\end{aligned}$$

Total dose received by intermodal transfer worker during transfer

$$\begin{aligned}\text{Dose} &= \text{dose at 2 m} + \text{dose at contact} \\ &= 1.62 \times 10^{-4} \text{ mSv} + 2.32 \times 10^{-4} \text{ mSv} \\ &= 3.9 \times 10^{-4} \text{ mSv}\end{aligned}$$

Assume worker is present for all 620 transfers during a one year period

Total dose received by worker

$$\begin{aligned}\text{Dose} &= \text{dose per event} \times \text{events per year} \\ &= 3.9 \times 10^{-4} \text{ mSv} \times 620 \\ &= 0.24 \text{ mSv}\end{aligned}$$

The dose received by the intermodal transfer worker during the transfer is 0.24 mSv which is less than the dose received by a driver.

Conclusions

The annual dose estimated to be received by a locomotive engineer is negligible. The annual dose to a worker engaged in intermodal operations (loading or unloading UFTP from railcar) is estimated to be 0.24 mSv/y. Both the locomotive engineer and intermodal worker have been calculated to received less dose than a truck driver.

References

- (1) Nuclear Waste Management Organization. 2013. Preliminary Assessment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel. The Corporation of the Township of Ignace, Ontario. Findings form Phase One Studies. NWMO Report APM-REP-06144-0009. November 2013.
- (2) Batters, S., K. Tsang and U. Stahmer. 2012. Generic Transportation Dose Assessment. Prepared for the NWMO by AMEC NSS Ltd. NWMO Report Number NWMO TR-2012-06. October 2012.

Appendix J – Public Dose Assessment

Generic Transportation Dose Assessment

NWMO TR-2012-06

October 2012

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U. Stahmer

NWMO

nwmo

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Generic Transportation Dose Assessment

NWMO TR-2012-06

October 2012

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ABSTRACT

Title: Generic Transportation Dose Assessment
Report No.: NWMO TR-2012-06
Author(s): S. Batters¹, K. Tsang¹, U. Stahmer²
Company: 1- AMEC NSS LTD, 2 - NWMO
Date: October 2012

Abstract

Canada, following a comprehensive decision making process, has chosen to develop a deep geological repository for the long term management of its used nuclear fuel. That used fuel will have to be safely and securely transported from its current interim storage facilities to the repository. The Nuclear Waste Management Organization (NWMO) is responsible for the transportation of the used fuel and has completed an update of an existing Dose Assessment Report.

The updated information will assist NWMO in evaluating the impact that transport of used nuclear fuel will have on the public and the environment. The findings from this updated assessment will provide a base case for NWMO as it plans a safe and secure transportation system, and will allow the Canadian Nuclear Safety Commission (CNSC) to evaluate compliance with its regulations for protecting public health and safety. The findings from this update will be used to support mode and route analyses, and defining transportation system operating procedures.

The Used Fuel Transportation Package (UFTP) is the reference transportation package for this updated assessment. NWMO is using the UFTP for its reference case in planning and engineering the repository design. NWMO, in order to perform a diligent assessment, conducted an analysis of potential doses that could be received by the public during road and railroad transport and for a hypothetical accident scenario.

In conducting this assessment, three road transport scenarios were identified which represent the range of pathways where the public potentially could receive levels of exposure or dose.

- Individuals residing or working along the transportation route
- Drivers or passengers riding in vehicles stuck in traffic gridlock and sitting next to a truck carrying an UFTP, and
- Persons sharing a rest area with a truck carrying a UFTP.

Similar scenarios were assessed for rail transportation.

The analysis in this report is generic, based on representative assumptions at this stage of planning where specific routes or geographic location of the repository site are unknown. The information will assist NWMO to assess the general level of exposure to the public from the UFTP operating under normal transportation conditions and to highlight opportunities where NWMO can incorporate ALARA principles to further reduce the exposure to the public.

The analysis is not intended to provide an exhaustive analysis of any specific set of scenarios. Scenarios can be defined that could result in different dose levels than those presented in this report. However, a detailed assessment of transportation impact scenarios is premature until

such factors as repository location, transportation mode and routes, population densities, transport package design, etc. are known.

The CNSC radiation dose limit for a member of the public was used to interpret the results of this assessment. The annual maximum dose or exposure rate to the public is specified in the regulations as 1 milliSievert per year (1 mSv/y). To put this number into perspective, the average Canadian receives approximately 1.8 mSv from background or natural radiation sources each year, and the dose from an abdominal X-ray is approximately 0.7 mSv.

A summary of the annual dose which a representative person¹ could receive based on typical transportation scenarios is shown in Table S-1 and Figure S-1. The CNSC regulatory limit and average annual dose from natural background radiation sources in the environment is shown.

The potential dose rates from the transport of used nuclear fuel are well below the CNSC regulatory limit and the dose received from natural sources.

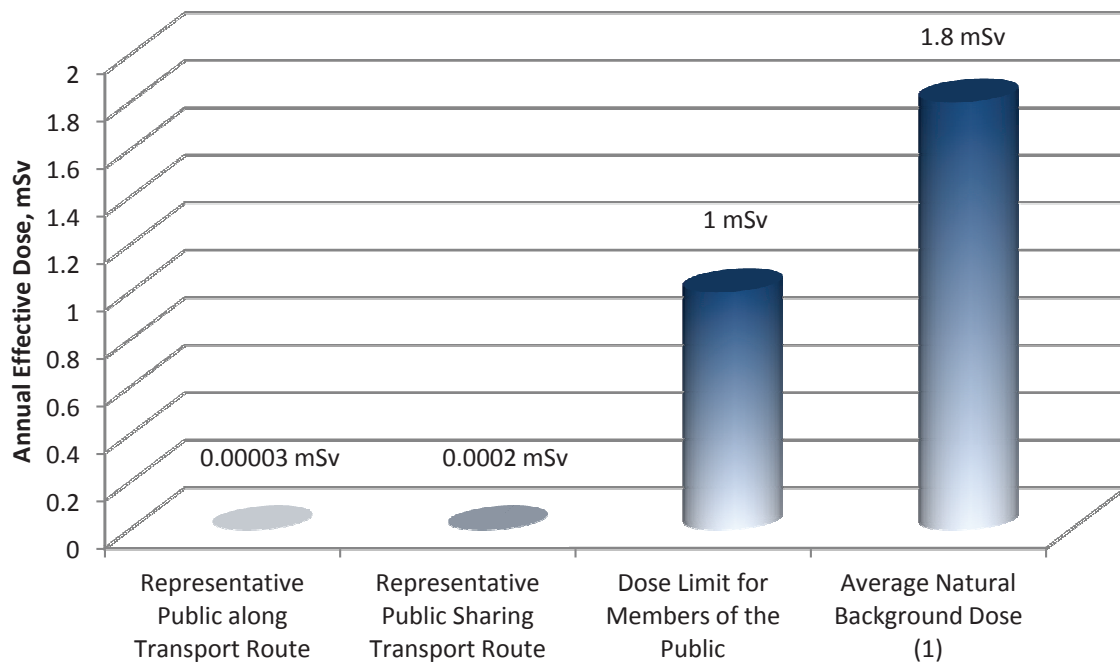
In completing the assessment of potential exposure to the general public, a hypothetical, yet highly unlikely, accident scenario was described and evaluated. This involved a potential release of radioactive material from the UFTP. Again, the standards established by the CNSC were used to conduct the assessment. The potential dose received by a person located near the accident was found to be dominated by direct external radiation exposure from the used fuel inside the transport cask. The dose contribution from potential releases was negligible in comparison.

In all cases, the maximum individual dose to the public under routine transport and accident conditions assessed was found to be less than the CNSC regulatory limit of 1 mSv per year. The public dose values calculated compare well with international experience.

Table S-1: Estimated Dose to a Representative Person due to Road Transport

	Dose [mSv/y]	Assumptions / Comments
Public along Transport Route	0.000032	Person living along route experiencing all 620 shipments
Public in Vehicle sharing Route	0.00018	Individual in vehicle travelling in front or behind cask for 1 hour for 1 shipment per month
	0.00022	Individual in vehicle travelling beside cask for 1 hour (i.e. traffic jam) for 2 shipments per year
Public in Vicinity of Rest Stop	0.00011	Person 10 m from cask for 30 minutes twice per year
Public in Vicinity of Unplanned Stop	0.00013	Person present near cask for 10 hours

¹ Recently, the International Commission on Radiological Protection defined the 'representative person' as an individual with characteristics that reflect those of the group that receives the highest doses from a particular source for a given radionuclide. The representative person is equivalent to, and replaces, the 'average member of the critical group', which was previously used as the basis for determining compliance with dose constraints for the public. This new terminology emphasizes that the value is based on a dose calculation for a person, who is almost always a hypothetical construct, since no actual person corresponds precisely to the group average.



Reference:

1. Average Natural Background Dose: Grasty, R.L. & LaMarre, J.R. 2004. The Annual Effective Dose from Natural Sources of Ionising Radiation in Canada. Radiation Protection Dosimetry (2004), Vol. 108, No. 3, pp. 215-226.

Figure S-1: Comparison of Dose to a Member of the Public

ACRONYMS AND DEFINITIONS

ALARA	As low as reasonably achievable. A radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods, taking into account social and economic factors. ALARA is not only a sound safety principle, but is a regulatory requirement for all radiation safety programs.
APM	Adaptive Phased Management. Canada's plan for long-term management of used nuclear fuel.
Burnup	A measure of how much energy has been extracted from a fuel bundle.
CANDU	CANada Deuterium Uranium. Canadian-invented, pressurized heavy water reactor. The acronym refers to its deuterium-oxide (heavy water) moderator and its use of natural uranium fuel.
CNSC	Canadian Nuclear Safety Commission, Canada's nuclear regulatory agency.
Conveyance	Any vehicle such as a truck, train or ship used to transport radioactive material.
DGR	Deep geological repository.
Effective Dose	A quantity calculated by multiplying the equivalent dose received by every significantly irradiated tissue in the body by a respective tissue weighting factor (this factor reflects the risk of radiation-induced cancer to that tissue) and summing together the individual tissue results to obtain the effective dose. Equivalent dose is the product of the absorbed dose (the energy transferred per unit mass) and a radiation weighting factor, which accounts for differences in biological impact of different radiation types.
IAEA	International Atomic Energy Agency, United Nations nuclear regulatory authority.
ICRP	International Commission on Radiological Protection, an advisory body providing recommendations and guidance on radiation protection.
MCNP	Monte Carlo N-Particle Transport Code. The software code used to calculate dose rates emitted by the UFTP. See Section 3.2 and Appendix A.
mSv	milliSievert. One thousandth ($\frac{1}{1000}$) of a Sievert. The Sievert is the International System of Units (SI) derived unit of radiation dose.
NEW	Nuclear Energy Worker. A person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public.
Type B	Type B packages are required for the transport of highly radioactive material including used nuclear fuel. These packages must withstand the conditions for normal transport and conditions expected in severe accidents without breach of containment.
UFTP	Used Fuel Transportation Package. The transportation package (or cask) used to assess the radiation dose reported in this study. The UFTP is currently certified by the CNSC as a Type B package. The cask was formerly referred to as the Irradiated Fuel Transportation Cask or IFTC.

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1. INTRODUCTION

Used nuclear fuel discharged from Canadian nuclear power reactors is currently stored at licensed interim storage facilities located at the reactor sites where it is produced. Adaptive Phased Management (APM), Canada's plan for long-term management of used nuclear fuel will place the used nuclear fuel into a deep geological repository (DGR). Implementation of APM requires the transport of the used nuclear fuel from the interim storage locations to the repository site.

A previous safety assessment of the used fuel transportation program examined public and occupational doses due to used fuel transportation by the three surface modes of transport, namely road, rail and water. The assessment formed part of the Environmental Impact Statement [1] on the deep geological repository concept for the long term management of Canada's used nuclear fuel which was subject to a federal environmental review process and public hearings in 1996 and 1997.

Recently, the ICRP [2] defined the 'representative person' as an individual with characteristics that reflect those of the group that receives the highest doses from a particular source for a given radionuclide. The representative person is equivalent to, and replaces, the 'average member of the critical group', which was previously used as the basis for determining compliance with dose constraints for the public [3]. This new terminology emphasizes that the value is based on a dose calculation for a person, who is almost always a hypothetical construct, since no actual person corresponds precisely to the group average. This assessment of the radiological dose to representative persons of the public (hereafter referred to as 'members of the public', 'general public', or 'public') due to used fuel transportation is a first step in assessing the radiological implications of the NWMO transportation program and its planning assumptions.

1.1 Assessment Purpose

The purpose of this work is to provide a generic assessment of the potential dose to the public due to used fuel transport in Canada. As the location of the eventual future DGR site is unknown, program specific calculations and risk assessments are premature. The intent of this assessment is to provide a starting point to address public concerns about the safety of the transportation system in a transparent manner. The information will provide a basis for decision making and program planning and to provide an input for design optimization of the components of the transportation system.

1.2 Assessment Scope

This assessment examines potential radiological individual effective dose (hereafter referred to as 'dose') received by members of the public resulting from the transportation of used nuclear fuel. Both routine operations and accident conditions are considered. For the purposes of this assessment, each transportation shipment is considered to start as the cask leaves the nuclear storage facility and is considered to end when the cask is ready to be unloaded at the APM repository site.

The scope of this assessment includes the following activities:

1. Calculation of external gamma and neutron dose rates from the Used Fuel Transportation Package (UFTP) for two reference fuel burnups of 220 and 280 MWh/kgU (see Section 3.2.5.2 for definition of burnup). The used fuel is assumed to be 30 years out-of-reactor. Both road and rail modes of transport are considered.

Note: the UFTP is certified to handle 10 year old fuel [4]. This analysis is based on the reference repository design which is based on 30 year old fuel [5].

2. Calculation of individual dose to members of the public resulting from the transportation of used nuclear fuel under normal and specified accident conditions.
3. Comparison of the results with international experience in radioactive materials shipments.

1.3 Assessment Basis

The calculation of individual dose to members of the public due to used fuel transportation is based on the following:

- a) Use of the reference transport cask, the UFTP certified by the Canadian Nuclear Safety Commission (CNSC),
- b) The UFTP is filled with 192 CANDU style 37 element used fuel bundles aged 30 years out-of-reactor. Used fuel stored at Atomic Energy of Canada Limited sites is typically not in 37 element CANDU fuel bundles and is beyond analyses presented in this report.
- c) Two used fuel burnups are considered: a burnup of 220 MWh/kgU used in calculations for normal conditions of transport and a burnup of 280 MWh/kgU used in calculations for accident conditions of transport. All irradiated fuel bundles in one UFTP are assumed to have identical burnup. Burnup is discussed in greater detail in Section 3.2.5.2.
- d) The road configuration consists of a tractor-trailer loaded with a single UFTP. An annual total of 620 shipments is assumed.
- e) The rail configuration consists of a train loaded with 10 UFTPs; 2 per railcar. An annual total of 62 shipments is assumed.
- f) Normal and accident conditions of transport as defined by the transportation regulations [6, 7]. The transportation regulations apply a graded approach to the specification of performance standards. These are characterized in terms of three general severity levels:
 1. Routine conditions of transport – *intended to cover the use and transport of packages under everyday/routine operations (i.e. conditions of transport in which there are no minor mishaps or damaging incidents to the packages)*, [8]
 2. Normal conditions of transport – *intended to cover situations in which the package is subjected to minor mishaps or incidents ranging in severity, but would continue its journey after having been subjected to these minor mishaps* (note: routine conditions of transport are a subset of normal conditions of transport) [8], and
 3. Accident conditions of transport – *intended to cover situations in which the package is subjected to incidents or accidents ranging in severity between those having a severity greater than that covered by normal conditions of transport, up to the maximum severity levels imposed by the transportation regulations under the applicable test requirements for the type of package concerned* [8].

2. RADIATION AND RADIOLOGICAL REGULATORY CONTEXT

2.1 Radiation

Radiation emitted by used fuel is in the form of high-energy particles (alpha particles, beta particles and neutrons) and photons (gamma rays). Alpha and beta particles cannot penetrate the thick steel walls of a transport cask. Hence, only gamma and neutron radiation levels present at various distances from a loaded used fuel transport cask are assessed in this document.

In addition, gamma rays may be produced when neutrons are being absorbed when they go through a shield material. This radiation is termed neutron capture gamma radiation and is also accounted for in the assessment.

Radiation dose, measured in Sieverts (Sv)², is a measure of the energy absorbed in human tissue and is generally used as an indicator of the potential radiation effect on the human body. Dose rate is the measurement of radiation exposure over a period of time. The dose rate decreases as the distance from the source increases and as protective shielding is added.

2.2 Regulatory Context

In Canada, the Canadian Nuclear Safety Commission (CNSC) sets radiological dose limits to protect the health and safety of persons and the environment. This is done by following the recommendations of the International Commission on Radiological Protection, which comprises some of the world's leading scientists and other professionals in the field of radiation protection, and by using many of the standards and guides of the International Atomic Energy Agency.

Dose limits are established for:

- a member of the general public,
- a “nuclear energy worker”, defined as a person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public, and
- a transportation package.

2.2.1 Regulatory Dose Limits

Effective dose limits for the public and nuclear energy workers set in the Radiation Protection Regulations [9] are shown in Table 1, below.

Table 1: Regulatory Individual Effective Dose Limits

Person	Period	Effective Dose
Nuclear energy worker, including a pregnant nuclear energy worker	(a) One-year dosimetry period	50 mSv
	(b) Five-year dosimetry period	100 mSv
Pregnant nuclear energy worker	Balance of the pregnancy	4 mSv
A person who is not a nuclear energy worker	One calendar year	1 mSv

² The unit used in this assessment is the milliSievert (mSv), which is equal to one thousandth ($1/1000$) of a Sievert.

2.2.2 Transportation Dose Limits

The transportation regulations set dose limits for transportation packages and the conveyances in which the packages are transported. Additionally, a distinction between shipments under exclusive use and not under exclusive use is made. Exclusive use is used to define shipments by a sole consignor with control over the shipment and all initial, intermediate and final loading and unloading operations [8] and describes NWMO's current planning assumptions for operating the transportation system. Shipments where these conditions cannot be met are not under exclusive use.

2.2.2.1 Dose Limits for Transportation Packages

For transportation packages, the radiation level at any point on the external surface of a transportation package shall not exceed 2 mSv/h, and shall not exceed 0.1 mSv/h at 1 m from the surface of the package [7]. For transportation packages under exclusive use, the radiation level at any point on the external surface of the transportation package shall not exceed 10 mSv/h [7].

2.2.2.2 Dose Limits for Conveyances

For conveyances, the radiation level at any point on the external surface of the conveyance shall not exceed 2 mSv/h, and shall not exceed 0.1 mSv/h at a distance of 2 m from the surface of the conveyance [7].

3. ANALYSIS METHODOLOGY AND MODELING ASSUMPTIONS

To calculate the potential dose to members of the public resulting from used fuel transportation, the dose rates at various locations and distances are calculated using a representative model of the cask (see Appendix A) in the three-dimensional Monte Carlo N-Particle transport code MCNP5 [10]. The dose rates calculated by the computer code are used as inputs to various transportation scenarios selected to represent typical interactions between the public and the used fuel. These include exposure to individuals living or working along the transport route, individuals in vehicles sharing the road, individuals present at stops along the transport route and transport accidents.

3.1 Transport Scenarios

Radiological dose to an individual from the UFTP is dependent on a number of factors which include: radioactivity of the radiological source (the used fuel); shielding present around the source (the transport cask); proximity to the radiological source; duration of exposure; and frequency of occurrence. To illustrate the range of potential doses to the public, this assessment examines dose due to used fuel transportation in the following categories:

- a) An individual living or working along a transport route;
- b) An occupant of a vehicle travelling the same transport route;
- c) An individual in the vicinity of a stopped used fuel transport vehicle; and
- d) An individual in the vicinity of a transport accident.

An initial set of representative scenarios in each of these categories is assumed and potential dose to the public is calculated for both road and rail transport. The scenarios are also similar to those used in other radioactive material transport risk assessments, such as those discussed in Section 6.3. Rationale for the exposure time, distance and frequency assumptions used in the analysed scenarios are detailed in Appendix A-5.

Transport accidents considered in this assessment are bounded by the tests for demonstrating ability to withstand accident conditions of transport in accordance with the Canadian [6] and International Transport Regulations [7]. Assumed transport scenarios are described in more detail in Section 3.1.1 for road transport and Section 3.1.2 for rail transport. Transportation accident scenarios are described in Section 3.1.3.

3.1.1 Road Transport

The weight of the fully loaded UFTP is such that only one cask can be transported on a tractor-trailer at a time in order to meet provincial transportation regulations. Hence, the road transport vehicle configuration consists of a tractor-trailer loaded with one UFTP enclosed under a weather cover. The weather cover assumed also provides shielding for neutron radiation emitted by the used fuel in the transport cask. The assumed configuration is illustrated in Figure 1. The facilities at the repository site are designed to process approximately 120,000 used fuel bundles per year resulting in approximately 620 road shipments per year.

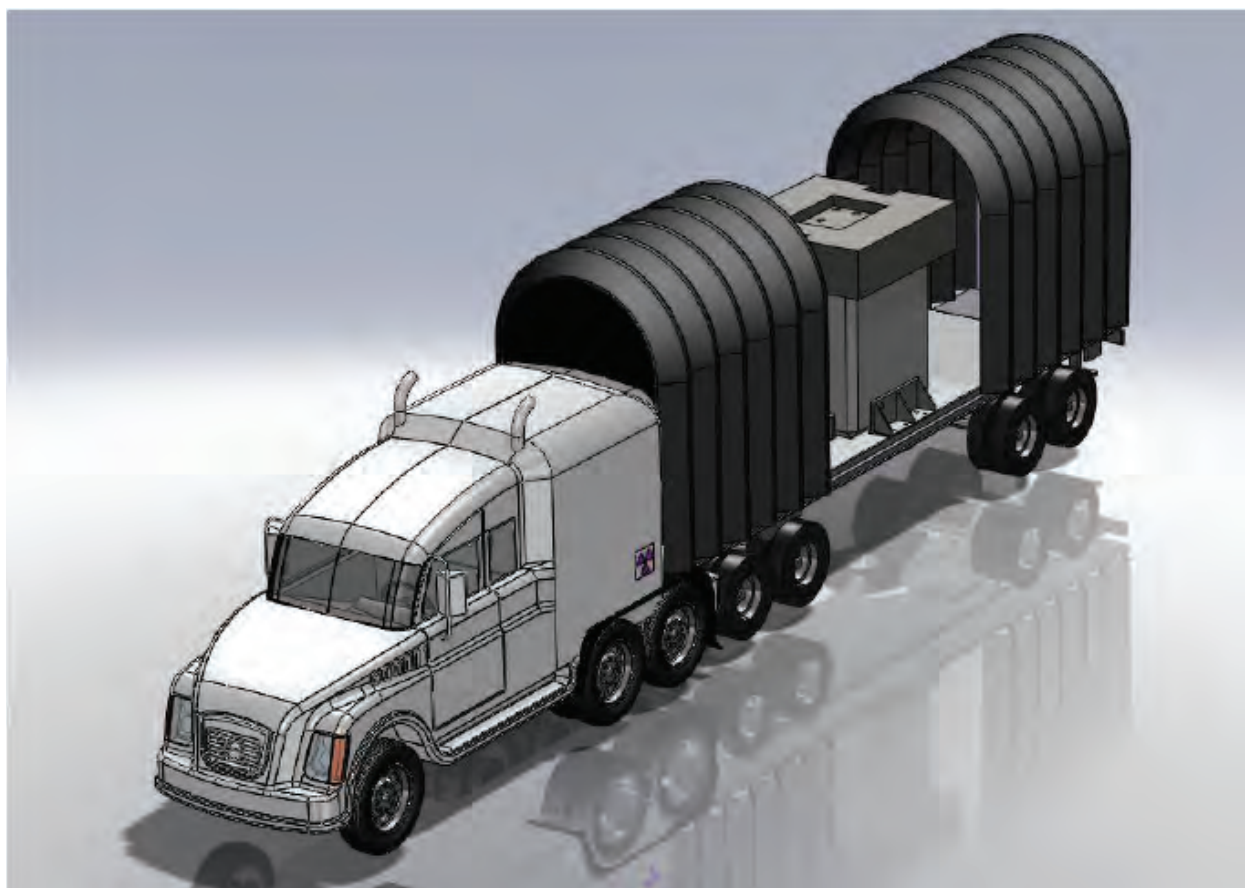


Figure 1: Typical Road Transport Configuration with Weather Cover Open

3.1.1.1 Individual along the Transport Route

Radiation exposure to an individual along a transport route varies with the speed at which the shipment passes by, the distance separating the individual and the cask as it passes by, and the number of shipments experienced by the individual over a period of time. The relationship between dose, distance and transport speed is discussed in detail in Appendix B.

For these calculations, the individual is assumed to be stationary, 30 m from the transport route. The tractor-trailer is assumed to be travelling past the individual at an average speed of 24 km/h (an assumed average speed of a vehicle travelling through a high population area). Conservatively, the individual along the route is assumed to be present for all 620 annual shipments. No credit is given for any incidental shielding (such as the walls of a building) that may be present between the resident and the UFTP.

3.1.1.2 Public Sharing Transport Route

For the public travelling in vehicles sharing the road with a used fuel shipment, two scenarios are investigated.

- a) A person in a vehicle travelling directly alongside the UFTP. This scenario was selected to represent a traffic jam or gridlock situation. A vehicle occupant (driver) is assumed to be at a distance of 10 m away from and travelling in a vehicle alongside the cask for a period of 1 hour. This scenario is assumed to occur twice to the same individual over a one year period.
- b) A person in a vehicle in front or behind a tractor-trailer carrying the UFTP. A vehicle occupant (driver) is assumed to be 23 m away from the cask and travelling in the same direction for a period of 1 hour. This scenario is assumed to occur six times to the same individual during a one year period.

In either scenario, no credit is given for any incidental shielding (such as the vehicle) that may be present between the receptor and the UFTP.

Exposure to individuals in oncoming traffic is considered to be of shorter duration than those in vehicles travelling in the same direction as the UFTP. Thus, only doses to individuals traveling in the same direction as the UFTP are examined as they are bounding in terms of maximum individual doses.

3.1.1.3 Public Near Rest Stop

A typical rest stop for the transport crew is assumed to be 30 minutes in duration. The tractor-trailer with one UFTP would be parked away from other vehicles and would be continuously monitored by one of the transport crew for security purposes. Rest stops would not involve vehicle refueling. Refueling operations are to take place at purpose-built "card-lock" refueling stations.

For the dose calculations, a member of the public is assumed to be located at a distance of 10 m away from the cask for the entire 30 minute rest stop. This scenario is assumed to occur twice to the same individual over a one year period.

3.1.1.4 Public Near Unplanned Stop

Unplanned stops are an inevitable component of transportation. They may be caused by mechanical breakdowns, a flat tire, weather, etc. Conservatively, an unplanned stop is assumed to be up to 10 hours in duration. For the dose calculations, a member of the public is assumed to be located at a distance of 30 m from the cask for the entire 10 hour unplanned stop. This scenario is assumed to occur once for any given individual during a one year period.

3.1.2 Rail Transport

Rail transport is expected to transport more UFTPs per shipment than the road network. The configuration of a train transporting UFTPs is assumed to consist of two locomotives, five railcars each loaded with two UFTPs with buffer cars on both ends, and a separate coach for the security escorts. Two UFTPs per rail car can readily be accommodated and a train

containing 5 railcars conveying a total of 10 UFTPs is assumed. This configuration is illustrated in Figure 2. The facilities at the repository site are designed to process approximately 120,000 used fuel bundles per year resulting in approximately 62 rail shipments per year.

3.1.2.1 Individual along Transport Route

The radiation exposure to an individual living or working along a rail route varies with the speed at which the shipment passes, the distance separating the individual and the 10 casks on the train as they pass by, and the number of shipments experienced by the individual over a period of time. The relationship between dose, distance and transport speed is discussed in detail in Appendix B.

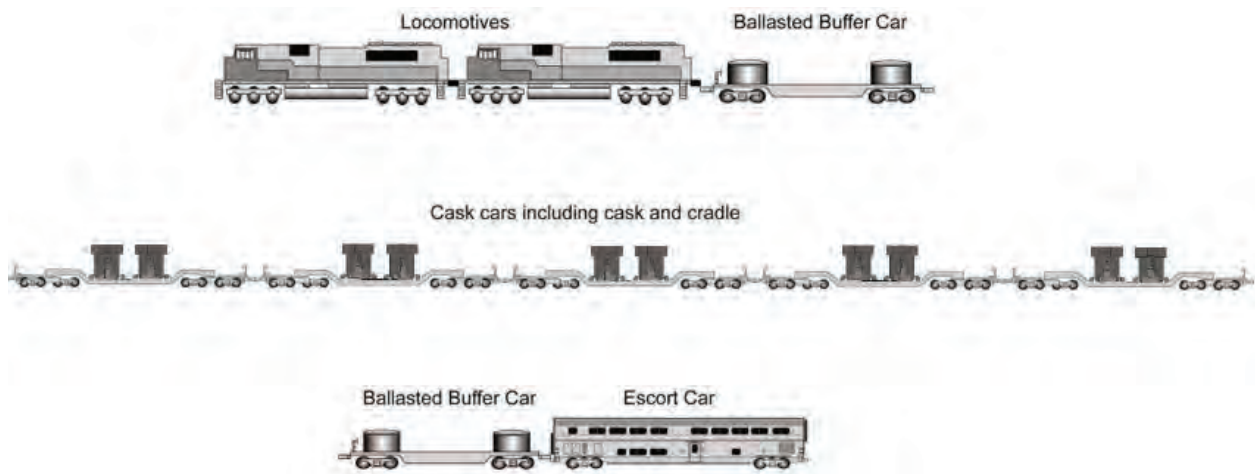


Figure 2: Typical Rail Transport Configuration

For these calculations, the individual is assumed to be stationary for the time the train passes their location (30 m from the rail route). The train is assumed to be travelling past the individual at an average speed of 24 km/h. Conservatively, the individual along the route is assumed to be present for all 62 shipments taking place over a one year period. No credit is given for any incidental shielding (such as the walls of a building) that may be present between the resident and the UFTP.

3.1.2.2 Public sharing Transport Route

In various parts of the country, rail lines run parallel to public roads. These rail lines may be in relatively close proximity to the road making it possible for an individual in a vehicle to travel adjacent to a train for a considerable distance.

For the dose calculations, a member of the public is assumed to be traveling alongside a used fuel rail shipment at a distance of 30 m from the casks in the middle of the train for 10 minutes. This scenario is assumed to occur twice to the same individual over a one year period. No credit is given for any incidental shielding (such as the vehicle) that may be present.

3.1.2.3 Public near Signal Stop

Railways throughout the world use signals to indicate to the train operator-engineer when to proceed. Signals indicate to the engineer the speed at which it is safe to travel. As such, trains will be required to stop at certain signals.

A signal stop along a rail line is assumed to be 10 minutes in duration. In general, locations of signal stops would be known and managed. For the dose calculations, a member of the public is assumed to be located at a distance of 30 m away from the casks placed in the middle of the train for the entire 10 minute signal stop. The same individual is assumed to be present for all 62 shipments taking place over a one year period.

3.1.2.4 Public near Unplanned Stop

Unplanned stops are an inevitable component of transportation. They may be caused by mechanical breakdowns, traffic incidents affecting the rail, etc. Conservatively, an unplanned rail stop is assumed to be 10 hours in duration. For the dose calculations, a member of the public is assumed to be located at a distance of 30 m from the casks placed in the middle of the train for the entire 10 hour unplanned stop. This scenario is assumed to occur once for any given individual during a one year period.

3.1.3 Transport Accidents

Transportation accidents may occur regardless of measures in place to minimize their occurrence. In this assessment, transportation accident severity is assumed to be bounded by the tests for demonstrating ability to withstand accident conditions of transport in accordance with the Canadian [6] and International Transport Regulations [7] (i.e.: the cask is assumed to remain intact with minimal release of content which is less than the regulatory limit). In this assessment, an area of 30 m radius is assumed to be immediately cordoned off around the site. Doses to members of the public located at various distances from 30 m to 800 m from the accident site over an 8 hour period are calculated.

A road accident is assumed to involve a single cask. The weather cover (which is assumed to provide neutron shielding during normal conditions) is assumed to have separated from the vehicle during the accident. A rail accident is assumed to involve two casks where the weather covers have separated from the railcar.

The IAEA regulations require that a Type B package such as the UFTP is able to withstand the cumulative effects of the following tests, in the given order:

- a) a 9 m drop onto an unyielding target so as to suffer maximum damage,
- b) a 1 m drop so as to suffer maximum damage onto a 15 cm diameter pin rigidly mounted perpendicular to the target, and
- c) a 30 minute fire with a temperature of at least 800°C, fully engulfing the specimen.

A Type B package such as the UFTP shall also be immersed under at least 15 m of water for a period of 8 hours and 200 m of water for a period of 1 hour.

The transportation regulations acknowledge that a small amount of leakage through the seals is allowable and define limits for this leakage under both normal and accident conditions. See Appendix C. From the Advisory Material [8]:

The design principle embodied in the Transport Regulations is that radioactive release from a Type B(U) package should be avoided. However, since absolute containment cannot be guaranteed, the purpose of specifying maximum allowable 'activity leak' rates is to permit the specification of appropriate and practical test procedures which are related to acceptable radiological protection criteria.

Based on the UFTP design, this potential leakage through the elastomeric seal between the body of the package and the lid and/or at the vent or drain ports [4] is also considered.

3.2 Description of the Monte Carlo N-Particle Model Components

A computer model of the UFTP was generated using the Monte Carlo N-Particle (MCNP) transport code. The Monte Carlo model used to calculate the radiation emitted by the UFTP consists of four major components: the used fuel (in bundles), the fuel module (the frame in which the used fuel bundles are held); the UFTP, and the weather cover which also provides neutron shielding. Each of these components is described in this section. The Monte Carlo model itself is described in detail in Appendix A.

3.2.1 Used Fuel Bundle

Canadian used nuclear fuel consists primarily of used CANDU fuel which is generated at commercial nuclear power reactors in Ontario, Québec and New Brunswick. In addition, there are very small quantities of used fuel from research and isotope-producing reactors in Canada. A CANDU fuel bundle consists of 28 to 37 elements containing uranium pellets. The elements are manufactured from Zircaloy 4, a zirconium metal alloy. Once filled with uranium pellets, they are sealed at both ends with zircaloy plugs and are welded together into a cylindrical matrix structure with plates at each end. A typical CANDU fuel bundle is shown in Figure 3. Each fuel bundle is approximately 500 mm long, 102 mm in diameter and weighs about 24 kg.

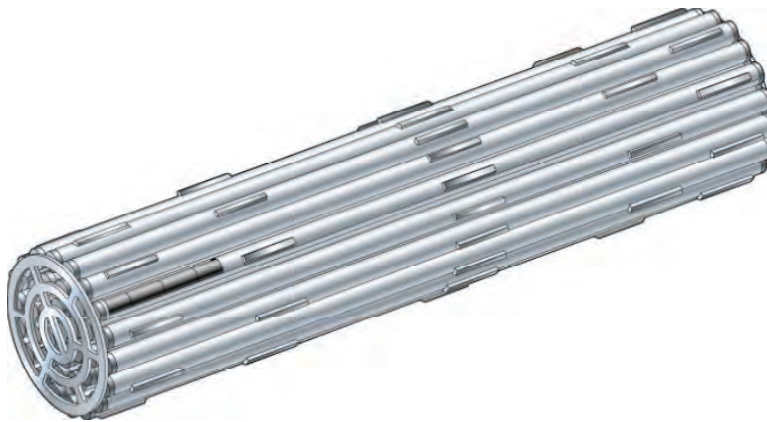


Figure 3: Typical CANDU Used Fuel Bundle

3.2.2 Fuel Module

Used fuel bundles are held inside the UFTP within fuel modules. The fuel module is a rack system currently used by OPG for holding used fuel bundles in interim storage. Each stainless steel fuel module contains 96 fuel bundles stored in linear pairs within 48 horizontal module tubes. These tubes are held in a rectangular framework. A typical module filled with used fuel bundles as illustrated in Figure 4 weighs approximately 2,500 kg.

3.2.3 Used Fuel Transportation Package

The UFTP was designed, tested, manufactured by Ontario Hydro in the mid 1980s. The cask design was first certified in 1985 by the Atomic Energy Control Board (the predecessor of the CNSC) under the regulations in place at that time and has been recertified under those regulations every 4 years since then. The most recent certificate was issued in July 2009 by the CNSC. An upgrade to the certificate demonstrating that the cask design meets current regulatory requirements is being prepared.

The UFTP is in the shape of a rectangular box and is designed to accommodate two stacked modules containing a total of 192 fuel bundles. The body and lid of the cask are manufactured from Type 304L stainless steel. The body is constructed from a single piece forging. The single piece lid is bolted to the body using 32 bolts. The impact limiter is made from redwood encased in a stainless steel shell. It is bolted to the top of the cask to protect the lid/body seal by reducing impact loading in the event of an accident. The impact limiter also serves as a heat shield to protect the cask seal during a fire [4]. An illustration of the UFTP is provided in Figure 4.

The overall cask dimensions are 1,881 x 1,556 x 1,824 mm (excluding protrusions and attachments) and the cask weighs approximately 35 tonnes when loaded with used fuel. The two long walls are 272 mm thick and the base, lid, and short walls are 267 mm thick. The cask can be lifted using trunnions on either side of the body and the lid is lifted via a central flange.

3.2.4 Weather Cover (Neutron Shield)

The stainless steel construction of the UFTP provides a very effective shield for gamma radiation; however, it is less effective for shielding neutrons. Although the UFTP design meets all regulatory dose requirements, a neutron shield (doubling as a weather cover and subsequently referred to as such) could be added around the cask to significantly reduce public and worker exposure. The doses from a UFTP are calculated with and without a weather cover in place. The weather cover assumed is a 10 cm thick high density polyethylene cover placed over top of the UFTP during normal transport operations. For accident scenarios, it is assumed that the weather cover has separated from the transport cask. All dose values for normal transportation conditions are provided with the weather cover in place.

3.2.5 Used Fuel Properties

All used fuel bundles inside the UFTP are assumed to be intact (undamaged) regular-length 37 element bundles. All used fuel bundles are assumed to have uniform decay and discharge burnup (see Sections 3.2.5.1. and 3.2.5.2, below).

3.2.5.1 Used Fuel Cooling Time

All fuel bundles inside the UFTP are assumed to be 30 years out-of-reactor.

3.2.5.2 Fuel Discharge Burnup

The radiation emitted by each fuel bundle after discharge from the reactor is dependent on the length of time spent in the reactor and is characterized by the fuel burnup. Burnup is a measure of how much fission energy has been produced per unit mass of fuel. At long decay time, irradiated fuel bundles with higher fuel burnup will emit more radiation.

Bundle-discharge burnups for Pickering A, Pickering B, Bruce A, Bruce B, and Darlington stations have been examined. A burnup of 220 MWh/kgU represents the highest of the average burnups at these plants [11]. A burnup of 280 MWh/kgU represents the 95th percentile of all discharged fuel bundles from Pickering A, Pickering B, and Bruce A stations; and the 99th percentile of all discharged bundles from Darlington and Bruce B stations.

The burnup for used fuel from Gentilly 2 and Point Lepreau stations is generally below 190 MWh/kgU [12], and hence is bounded by the OPG/Bruce Power values.

For the purposes of this assessment, a burnup of 220 MWh/kgU is assumed for annualized dose calculations. As an accident is assumed to represent a single occurrence, a burnup of 280 MWh/kgU is used for dose calculations in accident scenarios.

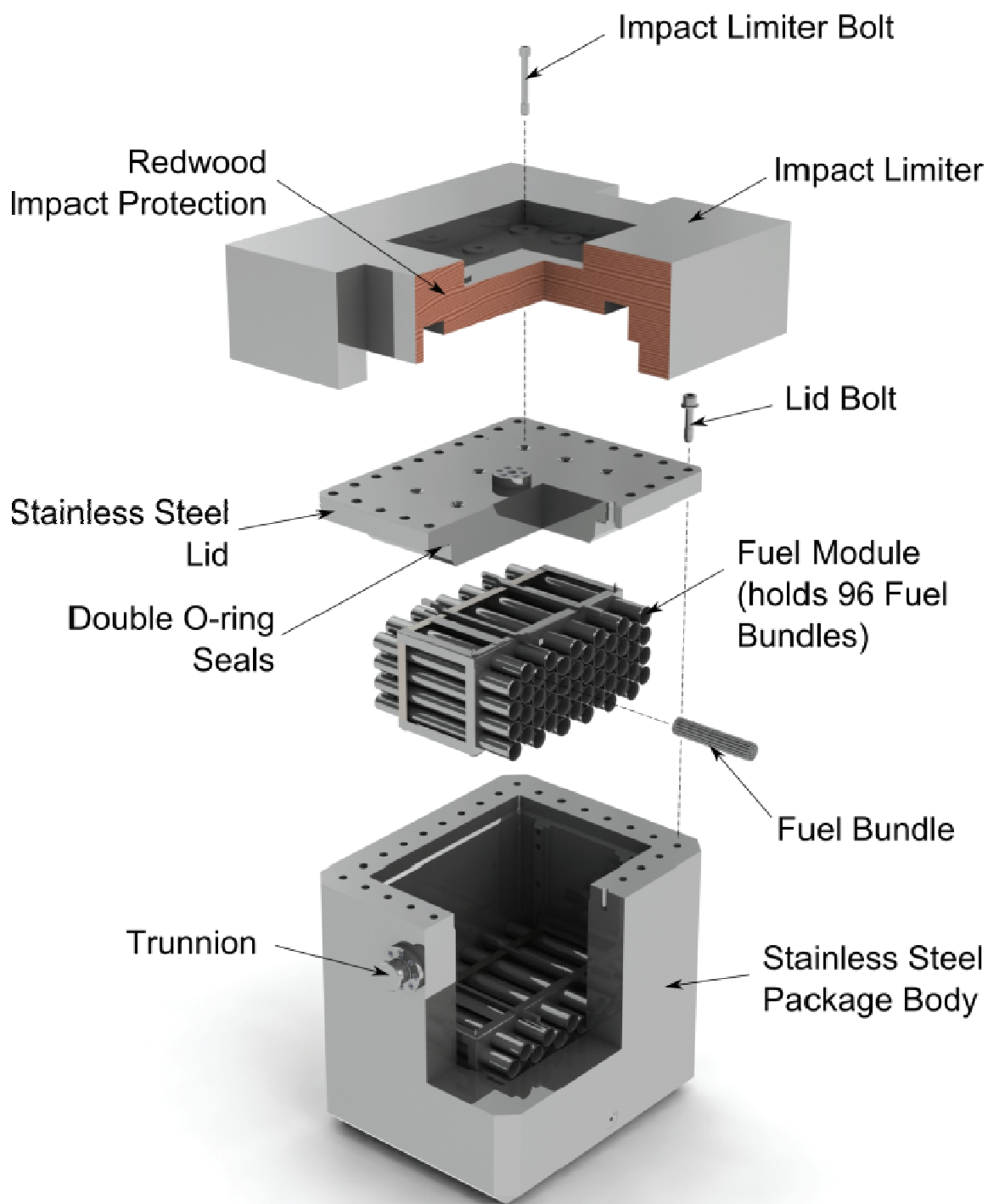


Figure 4: UFTP Assembly

3.2.5.3 Used Fuel Composition

For the purpose of shielding calculations, the fuel bundle physical composition is modeled as pure uranium oxide, i.e., fuel that has not undergone irradiation in a reactor. This assumption has no impact on the self-shielding effect on gamma rays but the neutron self-shielding effect of unirradiated uranium is slightly lower. This results in a conservatism of approximately 10% in the calculation of neutron doses.

3.3 Receptor Locations

The Monte Carlo model calculates dose rates external to the UFTP at discrete distances along lines radiating from 8 receptor locations on two planes: the cask mid-height (shown in red in Figure 5), and the mid-height of the lower fuel module (shown in blue in Figure 5). The receptor lines are illustrated in Figures 5 and 6. The receptors are located at the cask mid-plane and edge of both the short and long sides. This provides a dose profile of the cask with respect to the used fuel inside. At each receptor location, doses are calculated at the surface, and at distances of 0.3 m, 1 m, 2 m, 3 m, 10 m, and 30 m from the surface.

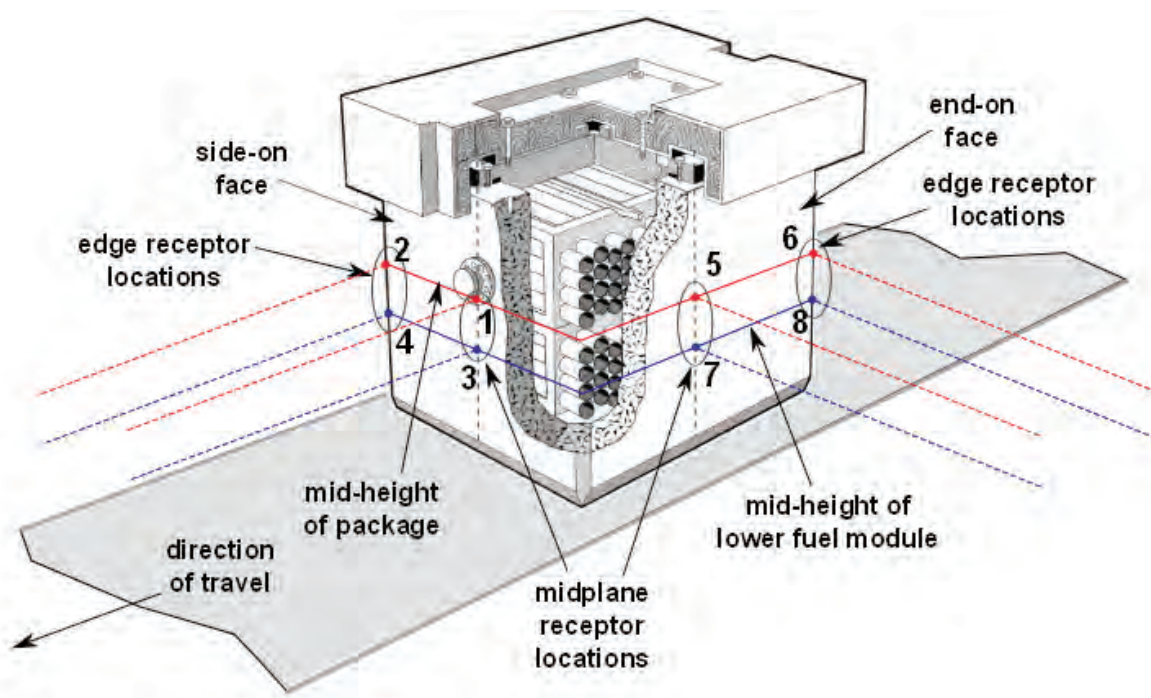


Figure 5: Dose Receptor Locations

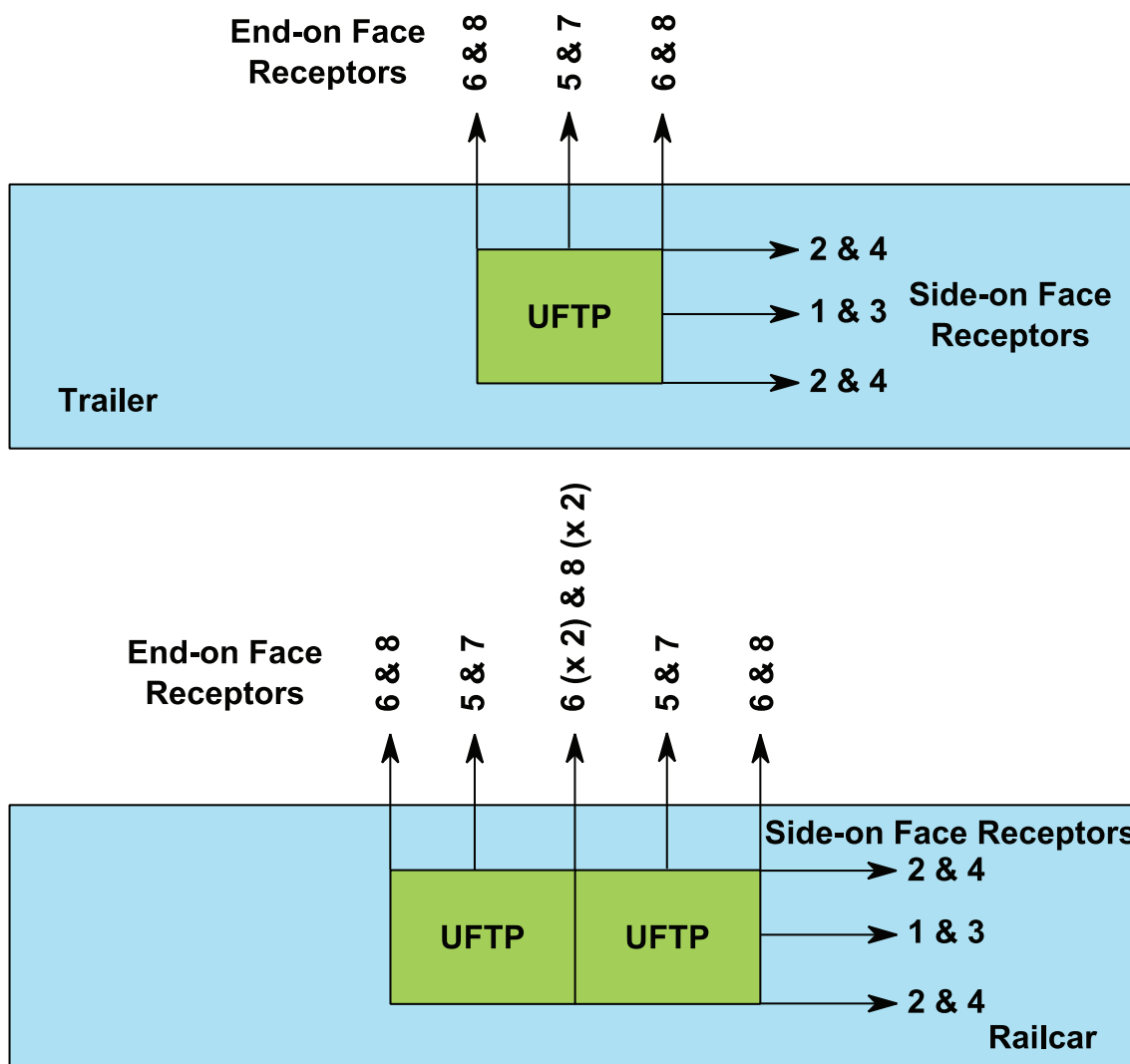


Figure 6: Monte Carlo Model Configuration and Receptor Locations

Note that the fuel bundles are situated parallel to the short wall of the UFTP and the ends of the fuel bundles face the long wall. Doses from the short wall are termed "side-on" and the long wall, "end-on" reflecting the relative location to the used fuel bundle orientation.

In both road and rail configurations, the UFTP is assumed to be situated with the side-on face in the direction of travel. Thus in the case of road transport, individuals travelling in front or behind the tractor-trailer would be exposed to the side-on face of the UFTP, whereas individuals along the transport route and individuals in passing vehicles would be exposed to the end-on face of the UFTP. Dose rates decrease as the receptor location moves from the centre of a UFTP wall because of the increased effective shielding thickness as one moves away from the perpendicular (see Figure 7). Hence if an individual were positioned facing a UFTP corner, even though both walls would be visible, the dose rate would be less than if they were perpendicular to a wall.

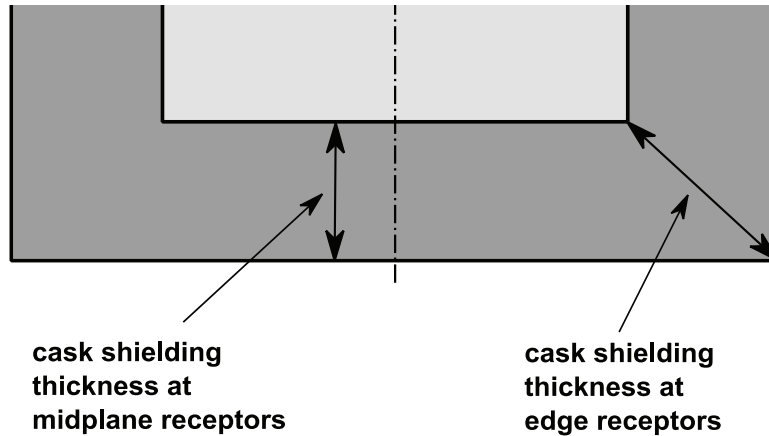


Figure 7: Shielding Thicknesses at Mid-plane and Edge Receptor Locations

3.4 Road and Rail Transportation Configurations

As described in Section 3.1.1, the road configuration consists of a single UFTP per tractor-trailer. The end-on faces of the UFTP are parallel to the direction of travel and the side-on faces are in line with the ends of the truck.

The rail configuration described in Section 3.1.2 consists of two UFTPs per rail car. Only a single railcar is modeled for simplicity. The cask orientation on the railcar is the same as the road transport arrangement: the end-on faces are parallel to the direction of travel and the side-on faces are in line with the ends of the train. Conservatively, the two casks are assumed to be touching each other as shown in Figure 6.

Radiation from the exposed side-on faces of the two cask rail configuration is assumed to be the same as for the single cask configuration. Radiation from the UFTP at the back must pass through its own shielding, in addition to the two shield walls of the UFTP in front and its used fuel contents. It has been shown that the radiation from the back UFTP would be negligible by the time it gets to the front UFTP's external forward face (see Appendices A-1.8 and A-4).

Dose rates at the edge of the cask are used to determine the contributions from a neighbouring cask. Hence, the dose rates at the plane between the casks are doubled to account for the dose-rate contribution from the adjacent cask.

4. MONTE CARLO MODEL DOSE RATE RESULTS

4.1 UFTP Dose Rate Results

The dose rates calculated at the various receptor locations described above are presented in this section. Both road and rail configurations are presented with and without the neutron shielding weather cover in place. These dose rate data are used to calculate individual public dose for the normal transport scenarios defined in Section 3.1 and external doses for the specified accident scenarios.

A comparison of the contact and 1 m dose limits specified in the transport regulations (see Section 2.2.2 and reference [7]) and the calculations for the UFTP (without the weather cover) is

provided in Table 2 for 220 MWh/kgU burnup fuel. For the cask, the maximum contact and 1 m dose rates have been calculated to be 0.061 mSv/h and 0.014 mSv/h respectively. These dose rates are significantly less than the regulatory limits of 2 mSv/h at contact and 0.1 mSv/h at 1 m presented in Section 2.2.2.

For 280 MWh/kgU burnup fuel, the maximum calculated contact and 1 m dose rates from the cask without the weather cover are 0.10 mSv/h and 0.026 mSv/h respectively (see Appendix A-3). Again, the dose rates are significantly less than the regulatory limits.

Table 2: Maximum Dose Rates from UFTP (without Weather Cover)

Distance from Cask	Regulations	Dose Rate [mSv/h]	
		220 MWh/kgU	280 MWh/kgU
Contact	2 or 10, under exclusive use	0.061	0.10
1 m	0.1	0.014	0.026

It was found that the dose rates calculated at the mid-height of the package (shown in red in Figure 5) exceeded the dose rates at mid-height of the lower fuel module (shown in blue in Figure 5). Thus, dose rates at package mid-height receptors (receptors 1, 2, 5 & 6) are used in public dose calculations.

4.1.1 Single UFTP on Tractor-Trailer

At the receptor distances assumed in the assessment, the maximum dose rates for the road configuration with the weather cover are calculated to occur at receptor location 1 (centre of the side-on face). The doses at various distances from this location for used fuel with a burnup of 220 MWh/kgU are tabulated in

Table 3 below and graphed in Figure 8. Similar tables for the remaining 7 receptor locations are presented in Appendix A-3. Note, all distances are measured from the external surface of the UFTP (the external surface of the weather cover is 0.377 m from the external surface of the UFTP).

Table 3: Dose Rates from UFTP at Receptor Location 1 (with Weather Cover)

Distance from Cask	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)		
	Neutron	Gamma (including capture gammas)	Total (±4%)
1 m	0.00045	0.0056	0.0060
2 m	0.00017	0.0022	0.0024
3 m	0.000094	0.0011	0.0012
10 m	0.000018	0.00011	0.00013
30 m	0.000003	0.000012	0.000015

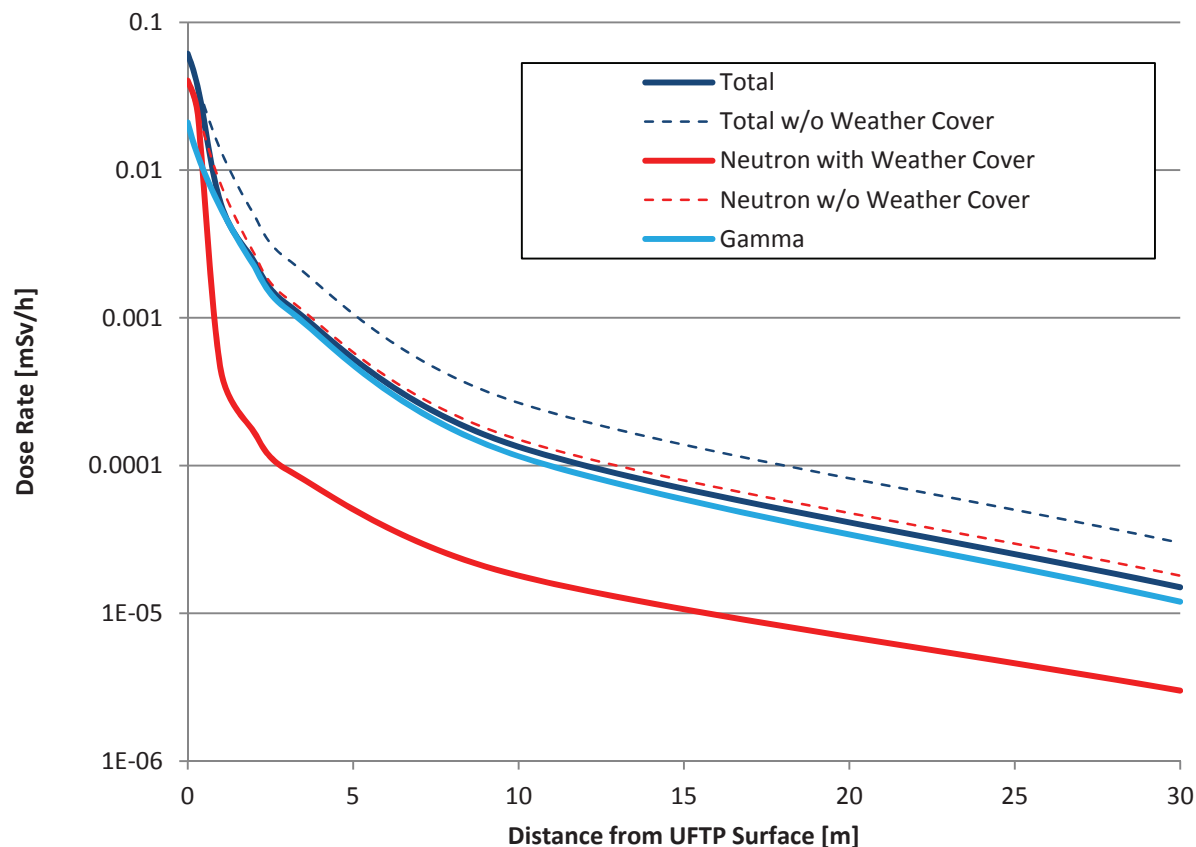


Figure 8: Dose Rates from UFTP at Receptor Location 1

4.1.2 Two UFTPs on Railcar

As discussed in Section 3.4, the dose rates on the side-on face are the same as in the tractor-trailer configuration. See receptor locations 1 through 4 in Figure 6 and Appendix A-3. The dose rate profile along the length of the platform of the rail car is represented by end-on dose rates. From the tables in Appendix A-3, the dose rates at the cask mid-height represent the bounding values.

Comparing the dose rates at receptor location 5 (Appendix A-3, Table A-3-5a) with double the dose rates at receptor location 6 (Appendix A-3, Table A-3-6a), it can be seen that the highest dose rates close to the UFTP occur at receptor location 5, directly facing the mid-plane of the cask, rather than in between the 2 casks. This is due to the fact that the contact dose rate at the edge receptors dips because of the increase in shielding thickness at the corners of the cask (see Figure 8). However, with increasing distance from the cask, the maximum dose rate shifts to the plane between the two casks at receptor location 6 (x 2). A comparison of dose rates at receptor locations 1, 2, 5, 6 and double the dose at receptor location 6 is provided in Figure 9.

All dose rates are significantly less than the regulatory limits for transportation packages (see Section 2.2.2).

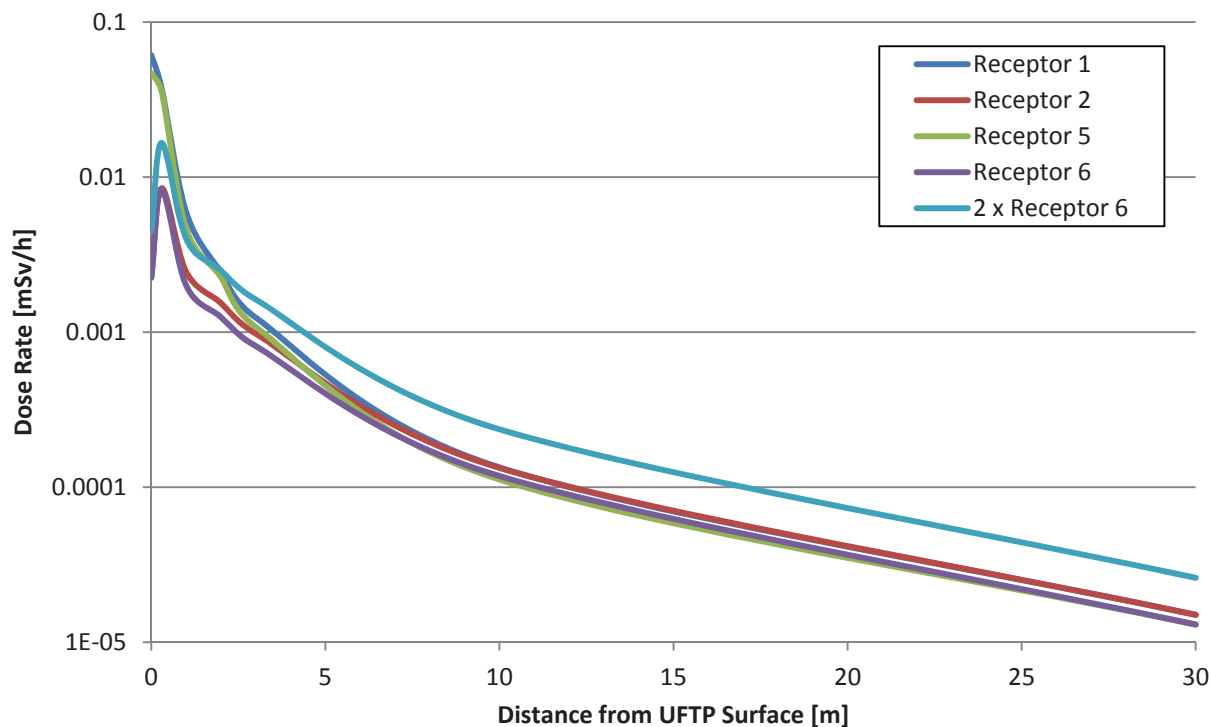


Figure 9: Comparison of Dose Rates at Receptor Locations 1, 2, 5 and 6

5. DOSE CALCULATIONS FOR TRANSPORTATION SCENARIOS

The dose rate results from the Monte Carlo model calculated in Section 4 are used to calculate public dose for each of the normal conditions of transport exposure scenarios presented in Section 3.1 and external radiation dose for the specified accident scenarios. To calculate individual external dose for a given scenario, the dose rate at the distance defined in the scenario is simply multiplied by the exposure time.

For example, from Table 3, the dose rate at 10 m from cask at Receptor location 1 is 0.00013 mSv/h. This means an individual standing 10 m away from the long side of the cask for one hour would receive a dose of 0.00012 mSv. If the individual is present at that location for 15 minutes, they would receive a dose of 0.000033 mSv, one quarter of the hourly dose. Likewise, an individual present at that location for 3 hours would receive a dose of 0.00039 mSv, or three times the hourly dose.

Exposure frequency must also be considered to calculate annual dose. From the previous example, an individual located 10 m away from the long side of the cask for 15 minutes receives a dose of 0.000033 mSv. Assuming the individual experiences this scenario 5 times during the span of a year, the individual then receives 5 times the dose received in the 15 minute exposure, or 0.00016 mSv per year.

As mentioned in Section 3.2.4, the weather cover provides additional shielding for neutron radiation. The weather cover is an integral part of the transportation system and the UFTP will be covered during all shipments.

Calculation of dose to an individual along a transportation route differs somewhat from the calculations described above. In this case, the individual is assumed to be stationary at a given

distance from the transport route. The dose rate the individual is exposed to will increase as the vehicle approaches, reaches a maximum when the transport cask(s) is (are) closest to the individual and then decreases as the vehicle continues on its route. The dose received is also dependent on vehicle speed; the faster the vehicle speed, the lower the dose because of the reduced exposure time.

The methodology used to determine dose to an individual along the transport route is presented in Appendix B. A vehicle speed of 24 km/h (the average speed of a vehicle in a high population area) is assumed for the calculation of public dose.

5.1 Dose due to Normal Road Transport

Dose rates used in the calculation of individual dose for each of the road transportation scenarios presented in Section 3.1.1 are tabulated in Table 4 below. These dose rates have been extracted from the Monte Carlo dose calculations for each receptor location presented in Appendix A-3. The dose rates calculated for each road transport scenario are provided in Table 5, and the resulting annual dose is presented in Table 6. An illustration depicting the road transportation scenarios is provided in Figure 10.

In all cases, dose due to the transportation of used nuclear fuel inside a UFTP is well below the dose limits set by the CNSC. The maximum exposure to a member of the public is estimated to occur during a traffic jam. The individual is assumed to be at distance of 10 m from the cask for one hour, twice per year. For this scenario, the dose is a factor of over 8,000 times less than the average annual natural background radiation dose in Canada.

Table 4: Dose Rates used in Road Mode Individual Dose Calculations

Fuel Bundle Burnup 220 MWh/kgU		
Receptor Location	Distance from Cask	Dose Rate (mSv/h)
1	10 m	0.00013
1	23 m	0.000030
1	30 m	0.000015
5	10 m	0.00011
5	15 m	0.000060
5	30 m	0.000013

Table 5: Public Dose for Road Transport Scenarios

Scenario	Distance from Cask	Exposure	Dose [mSv]	Assumptions / Comments
Public along Transport Route	30 m	1 shipment	0.000000051	Used fuel transport passing a stationary individual at 24 km/h (Location 5)
Public in Vehicle sharing Route	23 m	1 hour	0.000030	Individual travelling in vehicle behind transport cask for 1 hour (Location 1)
	10 m	1 hour	0.00011	Car driving beside cask for 1 hour (i.e. traffic jam) (Location 5)
Public in Vicinity at Rest Stop	10 m	30 minutes	0.000056	Person present near cask (Location 5)
Public in Vicinity of Unplanned Stop	30 m	10 hours	0.00015	Person present near cask (Location 1)

Table 6: Annual Public Dose due to Normal Road Transport

	Distance from Cask	Exposure (Number of Shipments)	Dose [mSv/y]	Assumptions / Comments
Public along Transport Route	30 m	620	0.000032	Individual along route experiencing all 620 shipments
Public in Vehicle sharing Route	23 m	6	0.00018	Individual in vehicle travelling in front or behind cask for 1 hour six times per year
	10 m	2	0.00022	Individual in vehicle travelling beside cask for 1 hour (i.e. traffic jam) for 2 shipments per year
Public in Vicinity at Rest Stop	10 m	2	0.00011	Person 10 m from cask for 30 minutes twice per year

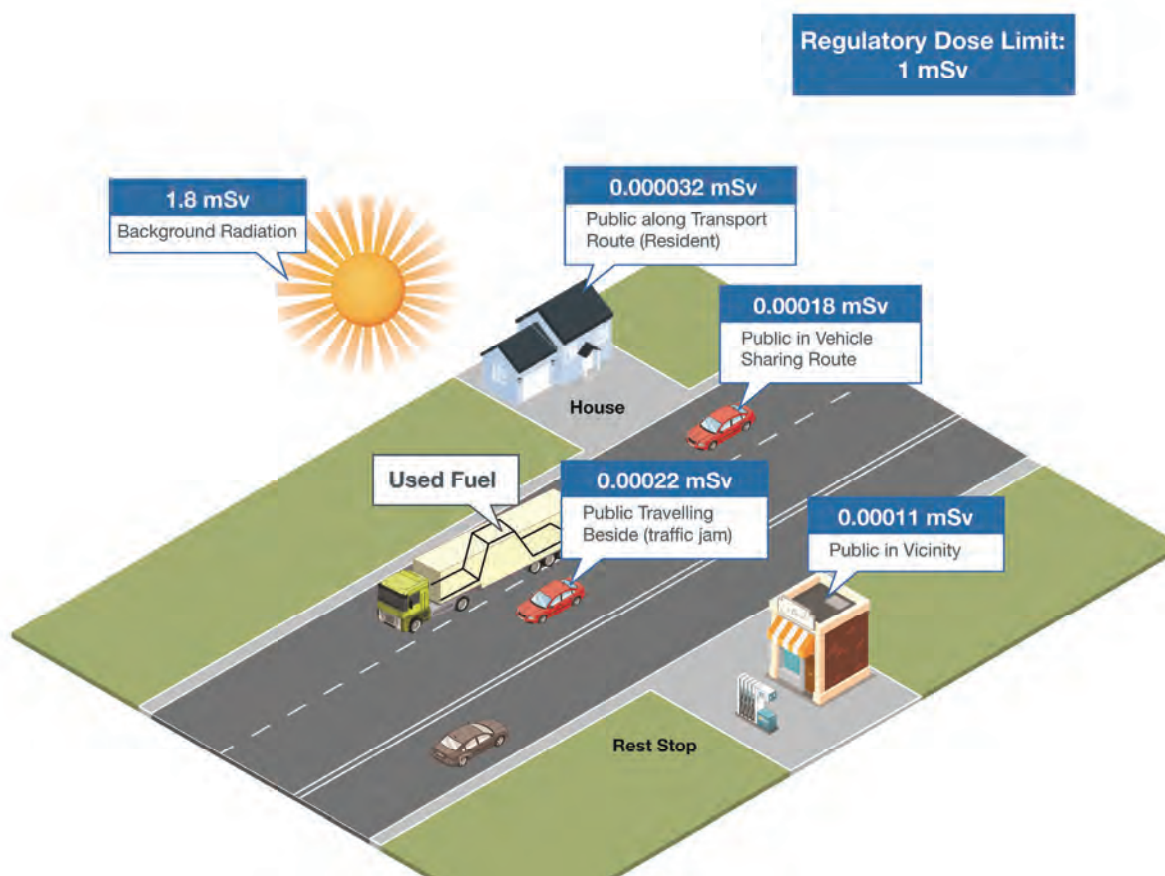


Figure 10: Annual Dose due to Road Transport

5.2 Dose due to Normal Rail Transport

Calculation of individual dose for each of the rail transportation scenarios presented in Section 3.1.2 is based on a single receptor location, Receptor 5 at a distance of 30 m from the middle railcar. The dose rate at this location is tabulated in Table 7 below. The doses calculated for each rail transport scenario are provided in Table 8, and the resulting annual dose is presented in Table 9.

In all cases, dose due to the transportation of used nuclear fuel inside the UFTP is well below the dose limits set by the CNSC. The maximum dose to a member of the public is calculated to be 0.00028 mSv per year to a person near a signal stop. The individual is assumed to be at distance of 30 m from the casks in the middle of the train for the 10 minute stop and to experience all 62 shipments per year. Even in this scenario, the dose is a factor of over 6,400 times less than the average annual natural background radiation dose in Canada.

Table 7: Dose Rate used in Rail Mode Individual Dose Calculations (with Weather Cover)

Fuel Bundle Burnup 220 MWh/kgU		
Receptor Location	Distance from Cask	Dose Rate (mSv/h)
6 (x 2)	30 m	0.000027

Table 8: Public Dose for Rail Transport Scenarios

Scenario	Distance from Cask	Exposure	Dose [mSv]	Assumptions / Comments
Public along Transport Route	30 m	1 shipment	0.00000051	Used fuel transport passing a stationary individual at 24 km/h
Public in Vehicle sharing Route	30 m	10 minutes	0.0000045	Individual travelling in vehicle alongside train for 10 minutes
Public in Vicinity of Signal Stop	30 m	10 minutes	0.0000045	Person present near casks
Public in Vicinity at Unplanned Stop	30 m	10 hours	0.00027	Person present near casks

Table 9: Annual Public Dose due to Normal Rail Transport

Scenario	Distance from Cask	Exposure (Number of Shipments)	Dose [mSv/y]	Assumptions / Comments
Public along Transport Route	30 m	62	0.000032	Individual along route experiencing all 62 shipments
Public in Vehicle sharing Route	30 m	2	0.000009	Individual travelling in vehicle alongside train for 10 minutes
Public in Vicinity at Signal Stop	30 m	62	0.00028	Person living near signal stop as all 62 shipments pass by

5.3 Dose due to Transport Accident

The ability of the cask to withstand the regulatory tests designed to simulate real world accident conditions was demonstrated through physical and analytical testing in the safety report [4]. Therefore in this assessment, the cask is assumed to be intact following an accident. The potential radiological dose to a member of the public in the unlikely event of an accident was assessed consistent with the regulatory test conditions and the assessment considers the following sources of radiation:

- radiation from the used fuel within the cask;
- radiation from an allowed minimal release of gas through the elastomeric seals; and
- an internal source of radiation due to the inhalation of this material.

The calculation to determine external dose is identical to the calculations for dose due to normal road transport in Section 4.1 with two exceptions. In this assessment, the cask is assumed to contain used fuel with a burnup of 280 MWh/kgU for the accident analysis rather than the burnup of 220 MWh/kgU as used in the analysis for normal conditions of transport, see Section 3.2.5.2. And the weather cover is assumed to have separated from the cask and is no longer able to provide neutron shielding. Dose rates at various distances along each receptor for both used fuel burnups are tabulated in Appendix A-3.

As the accident conditions stipulated in the transportation regulations are not expected to breach the cask seal, only permeation leakage of radionuclides in a gaseous form from within the cask is considered. From the Safety Analysis Report for the cask [4], two gaseous radioisotopes present in the cask, namely Krypton-85 (Kr-85) and Hydrogen-3 (H-3, known as 'tritium'), were found to be important. The UFTP radioactive material inventory used in this assessment includes additional radioisotopes of elements that will or may be gaseous under the accident conditions considered, however due to their relative low radioactivities compared to Kr-85 and H-3 and very low dose per activity uptake, the dose contribution from these radionuclides would be much less than from Kr-85 and H-3.

The assumed leakage rates of Kr-85 and H-3 under accident conditions is based on the testing and assessment of the UFTP design [4]. These calculations have been adjusted to account for the UFTP radioactive material inventory of fuel aged 30 years out-of-reactor [11] and more recent effective free inventory fraction assumptions made in references [13] and [14]. The gaseous radioactive material would be released at a very slow rate. It is assumed that the public would be cleared from the immediate area, thus the closest member of the public exposed would be located at a distance of 30 m. It is also assumed that the public within an 800 m radius from the accident site would be exposed to any potential release for 8 hours.

Using the calculated release rate and exposure time, the methodology detailed in the Canadian Standards Association (CSA) Guidelines N288.2-M91 (Reaffirmed 2008) [15] was used to calculate doses to members of the public under the specified accident conditions. Gaseous material released from the cask is assumed to be dispersed by ambient weather conditions. Conservatively, weather conditions leading to minimal dispersion (i.e. minimal dilution of radioactivity concentration in the air; less dispersion equals greater dose) were assumed in this assessment.

Calculation of public dose resulting from accident conditions are described in detail in Appendix C. The results for an accident involving a UFTP containing used fuel of burnup 280 MWh/kgU for road transport are shown in Table 10 and Figure 11 for the UFTP only (without weather cover). As stated in Section 3.2.4, the weather cover is assumed to separate from the cask during the accident and is not credited for providing any additional shielding.

Table 10: Potential Doses from Specified Road Transport Accident Conditions

Distance – UFTP to Receptor	30 m	40 m	50 m	75 m
Dose from H-3 [mSv]	0.000026	0.000016	0.000011	0.000005
Dose from Kr-85 [mSv]	0.00000007	0.00000004	0.00000003	0.00000002
External Dose from material remaining in UFTP [mSv]	0.00046	0.00026	0.00016	0.000073
Total Dose [mSv]	0.00048	0.00027	0.00018	0.000078

Distance – UFTP to Receptor	100 m	300 m	500 m	800 m
Dose from H-3 [mSv]	0.000003	0.000000	0.000000	0.000000
Dose from Kr-85 [mSv]	0.00000001	0.00000000	0.00000000	0.000000
External Dose from material remaining in UFTP [mSv]	0.000041	0.000005	0.000002	0.000001
Total Dose [mSv]	0.000044	0.000005	0.000002	0.000001

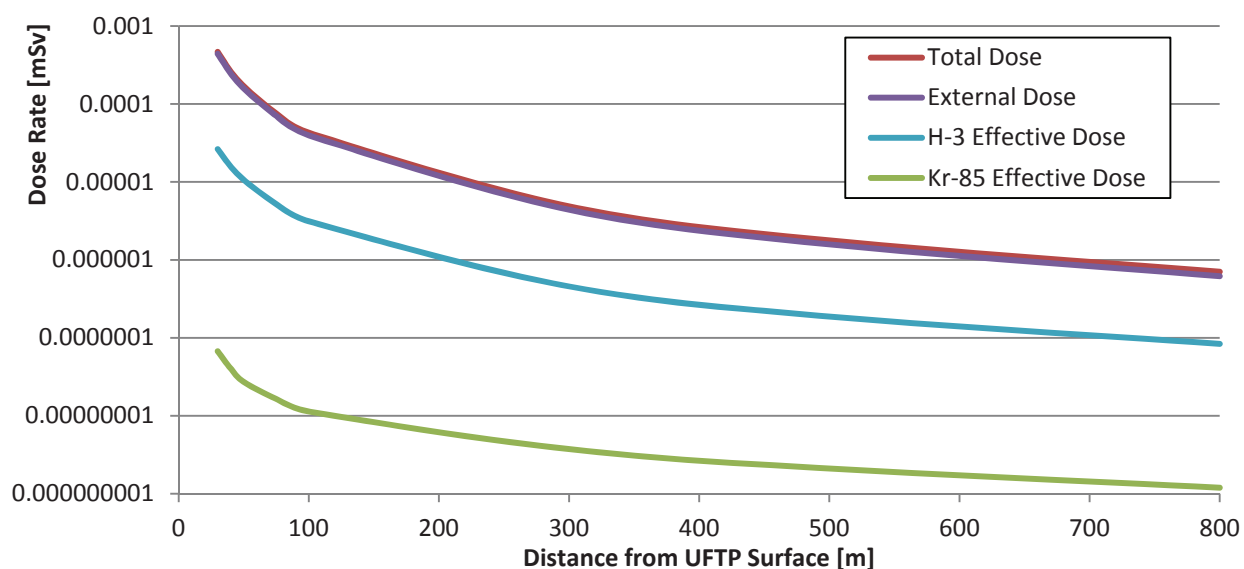


Figure 11: Potential Doses from Specified Road Transport Accident Conditions

For rail transport, the same methodology as for road transport was used, with the exception that two UFTPs are assumed to be affected by the accident (even if all 10 casks transported on the train to be affected, the dose contribution from potential releases is less than the direct dose rate from one cask). The potential gaseous radioactive material release inventories are doubled for the two casks affected. The results for a rail accident involving UFTPs containing used fuel of burnup 280 MWh/kgU for road transport are shown in Table 11 and Figure 12. The total dose resulting from an accident, either road or rail, is dominated by direct external radiation from radioactive material remaining within the UFTPs; the dose contribution from potential releases is negligible in comparison.

Table 11: Potential Doses from Specified Rail Transport Accident Conditions

Distance – UFTP to Receptor	30 m	40 m	50 m	75 m
Dose from H-3 [mSv]	0.000053	0.000032	0.000021	0.000010
Dose from Kr-85 [mSv]	0.00000013	0.00000008	0.00000005	0.00000003
External Dose from material remaining in UFTP [mSv]	0.00091	0.00051	0.00033	0.00015
Total Dose [mSv]	0.00097	0.00055	0.00035	0.00016

Distance – UFTP to Receptor	100 m	300 m	500 m	800 m
Dose from H-3 [mSv]	0.000006	0.000001	0.000000	0.000000
Dose from Kr-85 [mSv]	0.00000002	0.00000001	0.000000	0.000000
External Dose from material remaining in UFTP [mSv]	0.000082	0.000009	0.000003	0.000001
Total Dose [mSv]	0.000088	0.000010	0.000004	0.000001

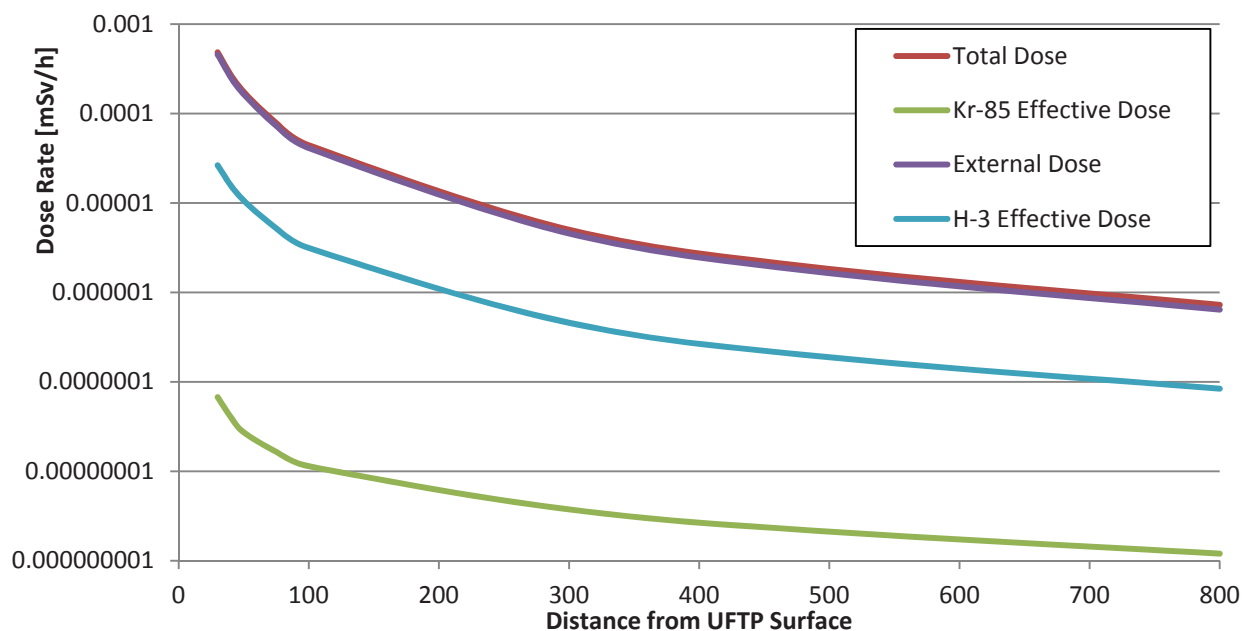


Figure 12: Potential Doses from Specified Rail Transport Accident Conditions

The highest dose to a member of the public due to the transportation accident scenarios assessed results from an individual located at a distance of 30 m from a rail accident for 8 hours. Even in this scenario, the dose exposure is a factor of over 1,800 times less than the average annual natural background radiation dose in Canada.

In all cases, public dose from the specified accident conditions due to the transportation of used nuclear fuel are well below the dose limit of 1 mSv per year set by the CNSC.

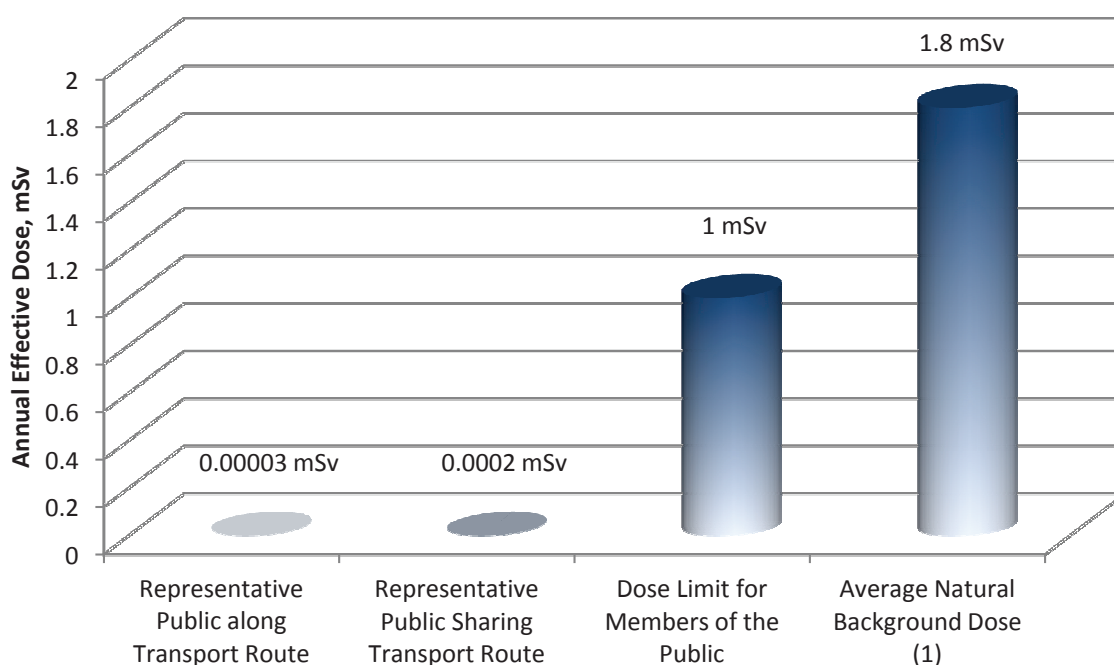
6. DISCUSSION OF RESULTS

6.1 Dose Assessment Summary

As described in Section 5, doses calculated for individuals due to the transportation of used nuclear fuel are very low and well below regulatory limits and natural or background radiation levels.

As shown in Tables 5 and 8, the dose to an individual along a transportation route exposed to all shipments is considerably less than that to an individual sharing the transport route or at a transport stop. Even though the number of casks the individual along the transport route is exposed to is high (620 casks), the total exposure time is very small. See Appendix B.

An individual along a transportation route has been calculated to receive a dose of 0.000032 mSv per year due to transportation, a factor of safety of 30,000 compared to the regulatory limit of 1 mSv. The relationship between regulatory dose, average natural background dose, and potential annual doses to an individual along a transportation route and a member of the public in a vehicle sharing the transportation route is shown in Figure 13.



Reference:

1. Average Natural Background Dose: Grasty, R.L. & LaMarre, J.R. 2004. The Annual Effective Dose from Natural Sources of Ionising Radiation in Canada. Radiation Protection Dosimetry (2004), Vol. 108, No. 3, pp. 215-226.

Figure 13: Comparison of Dose to a Member of the Public

6.2 Additional External Shielding

The Monte Carlo calculations (see Figure 8) show that the cask itself provides very effective shielding for gamma radiation, but is less effective for neutron radiation. Although radiation levels external to the cask are well below regulatory limits, the addition of a 10 cm thick layer of

high density polyethylene inside the weather cover as a neutron shield further reduces the radiation levels by approximately 75%. This additional shielding is simple and cost effective to implement and could be considered in As Low As Reasonably Achievable (ALARA) assessment of the final used fuel transportation system.

6.3 Comparison of Dose Results with Ontario Power Generation Environmental Impact Statement and International Experience

A comparison of several radioactive material transportation risk assessments was conducted and is discussed in Sections 6.3.1 to 6.3.5 below. It should be noted that only dose results are compared; the inputs and assumptions in each comparison case are different from the current assessment (e.g. type and quantity of fuel, transport container specifics, number of shipments, etc), and hence direct comparison may not be valid.

6.3.1 Ontario Hydro Nuclear 1994 Assessment

A previous safety assessment of the used fuel transportation system [1] by Ontario Hydro Nuclear (OHN, now known as Ontario Power Generation) examined transportation to a central repository site using several modes of transport including all road, mostly rail and mostly water.

The previous transportation safety analysis formed part of the Environmental Impact Statement [1] on the repository concept which was subject to a federal environmental review process and public hearings in 1996 and 1997.

The comparable OHN 1994 assessment results and corresponding current assessment results are shown in Table 12.

**Table 12: Comparison of Maximum Individual Annual Dose Results
– OHN 1994 Assessment**

Mode	Receptor	Maximum Individual Annual Dose [mSv]	
		OHN 1994 Assessment	Current Assessment
Road	Person present at a truck stop	0.070	0.00011
Road	Individual along the route	0.0041	0.000032
Rail	Individual along the route	0.0003	0.000032

All of the results for the current assessment are less than those reported in the OHN 1994 assessment. The differences in the input assumptions are briefly described below.

For truck stops, the OHN 1994 assessment assumed that the maximally exposed individual would be at a distance of 25 m from the UFTP transport vehicle, for 50% of the time, and that one-third of the shipments would stop for one hour at any particular truck stop. The current assessment assumes a member of the public is located a distance of 10 m away from the package for two 30 minute rest stops per year.

For individuals along the road routes, the OHN 1994 assessment dose was calculated for a distance of 8 m from the shipment path to the individual. The corresponding distance in the current assessment is 30 m.

The assumptions used in the rail calculations for individuals along the route in the OHN 1994 assessment are not specified in the documentation.

6.3.2 United States Department of Energy (DOE) Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain

The US DOE Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain [16] included an assessment of doses from shipments of spent nuclear fuel by truck and rail from 72 commercial and 5 DOE sites throughout the United States to a geologic repository at Yucca Mountain, Nye County, Nevada.

The Yucca Mountain assessment included estimates of maximum individual doses. A comparison of relevant receptors between the Yucca Mountain and current assessments is shown in Table 13.

Table 13: Comparison of Results for Maximum Individual Annual Doses – Yucca Mountain

Mode	Receptor	Maximum Individual Annual Dose [mSv]	
		Yucca Mountain	Current Assessment
Road	Individual along route	0.0025	0.000032
Road	Person in traffic jam ^a	0.16	0.000112
Road	Rest stop – public in vicinity	0.67	0.00011
Rail	Individual along route	0.00067	0.000032

^a Single shipment dose rather than annual dose.

All of the results for the current assessment are less than those of the Yucca Mountain assessment.

The time spent in the traffic jam for the Yucca Mountain assessment was not specified, and may be greater than that assumed for the current assessment. For the rest stop – public in vicinity, the Yucca Mountain assessment assumed that the same person is present at the same stops for 50% of all shipments, whereas this assessment assumes a member of the public is located a distance of 10 m away from the package for two 30 minute rest stops per year. Input assumptions used in the Yucca Mountain assessment for the other scenarios compared were not found available in the public domain.

6.3.3 United Kingdom National Radiological Protection Board Assessment of Radiation Risks to Transport Accident Responders

The United Kingdom National Radiological Protection Board (NRPB) conducted an assessment of radiation risks to emergency service personnel responding to radiation transport accidents for road and rail routes [17]. It was found that the maximum dose from the release of radioactive materials to a responder at the outer cordon set up at a distance of 45 m around an accident involving MAGNOX reactor used fuel in a Type B container would be 0.0000009 mSv. This can also be considered the maximum dose to a member of the public. The corresponding dose at this distance in this assessment is 0.000013 mSv. The UK assessment assumed an exposure time of 1 hour, whereas the current assessment assumed 8 hours. Factoring in the difference in exposure time, the current assessment value would be approximately twice the NRPB estimate.

6.3.4 World Nuclear Transport Institute Study

The World Nuclear Transport Institute (WNTI) conducted a global assessment in 2006 of the likely doses to various types of workers in nuclear fuel cycle transport operations and also to members of the public based mainly on the extensive experience of actual operations [18].

A comparison of relevant receptors between the WNTI and current assessments is shown in Table 14.

Table 14: Comparison of Results for Maximum Individual Annual Doses – WNTI

Mode	Maximum Individual Annual Dose [mSv]	
	WNTI	Current Assessment
Road	<0.0040	0.00022
Rail	<0.0060	0.00028

The current assessment numbers are smaller than the WNTI assessment numbers, however the WNTI values are 'less than' (denoted by the symbol '<').

6.3.5 Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) Paper on Transport of Radioactive Material in Germany

GRS conducted a study on radiation exposures of workers and the public associated with the transport of radioactive material in Germany [19].

A comparison of relevant receptors between the GRS and current assessments is shown in Table 15.

Table 15: Comparison of Results for Maximum Individual Annual Doses – GRS

Mode	Maximum Individual Annual Dose [mSv]	
	GRS	Current Assessment
Road	0.01	0.00022
Rail	0.01	0.00028

The results for the current assessment are less than the GRS assessment values. Details on the relevant GRS factors (e.g. distances, exposure times, etc) were not provided in the GRS paper; hence direct comparisons may not be valid.

6.3.6 Summary of Comparison with Dose Results with International Experience

A summary of the comparisons presented in this section is provided in Table 16.

Table 16: Summary of Comparison with Dose Results with International Experience

Mode	Receptor	Maximum Individual Annual Dose [mSv]					
		Current Assessment	OHN 1994	Yucca Mountain	UK NRPB	WNTI	GRS
Road	Individual along route	0.000032	0.0041	0.0025	-	-	-
Road	Person in traffic jam ^a	0.00013	-	0.16	-	-	-
Road	Rest stop – public in vicinity	0.00011	0.070	0.67	-	-	-
Road	Individual near accident	0.000013	-	-	0.0000009	-	-
Road	Maximum of all receptors	0.00022	-	-	-	<0.0040	0.01
Rail	Individual along route	0.000032	0.0003	0.00067	-	-	-
Rail	Maximum of all receptors	0.00028	-	-	-	<0.0060	0.01

^a Single shipment dose rather than annual dose.

7. CONCLUSIONS

7.1 Dose Rates from the UFTP

Dose rate profiles of the UFTP containing used fuel with burnups of 220 and 280 MWh/kgU were calculated using the Monte Carlo N-Particle computer code. It was determined that the dose rates emitted by the UFTP for both used fuel burnups are extremely low and are significantly below CNSC regulatory limits.

7.2 Public Dose due to Used Fuel Transport

Doses for groups of most exposed individuals were calculated including: individuals along the transport route; persons sharing the transport route; and persons at rest/signal stops. A maximum individual dose of 0.00028 mSv was calculated to result from residing near a rail transportation signal stop, significantly below average natural or background radiation levels [20] and typical X-ray examinations [21].

Dose resulting from potential transport accidents bounded by the conditions defined in the Canadian and International Transport Regulations were also assessed. It was determined that the potential dose received by a person near such an accident is dominated by direct external radiation exposure from the used fuel inside the transport cask, with the dose contribution from potential releases being negligible in comparison.

In all cases, the maximum individual dose to the public under routine transport and accident conditions was assessed to be less than the regulatory limit of 1 mSv per year.

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APPENDIX A THE MONTE CARLO MODEL OF THE UFTP AND DOSE RATE RESULTS

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A-1 Description of the Monte Carlo Model

Monte Carlo N-Particle (MCNP) transport code is a general-purpose computer code used for calculation of neutron, photon, electron, or coupled neutron/photon/electron transport. The code is used in many areas of application, including radiation protection, radiation shielding, radiography, medical physics, and nuclear criticality safety. In this case, the code is used to calculate dose rates at various locations and distances from the UFTP based on the flux spectra. A detailed description of the Monte Carlo model is provided in this appendix. MCNP5 version 1.3 is used in the calculations.

MCNP was originally developed at the Los Alamos National Labs (LANL) in the late 1970's and has since become an international standard for neutron and photon radiation transport simulations. Though currently MCNP is not formally qualified under the AMEC NSS established processes for qualification of computer codes used in safety analyses, its continuous refinement and extensive international use over the last three decades affirms that it has all the attributes of a qualified code and is considered the best tool for the current task of assessing neutron and gamma dose rates from UFTP. Further, MCNP is frequently used in the field of Medical Physics for calculations of beta, gamma and neutron dose rates to human tissue; as such, its accuracy for the current task is sufficient.

The Monte Carlo model of the UFTP is developed in 2 stages.

1. UFTP without the Impact Limiter
2. UFTP with the Impact Limiter and covered completely inside the weather cover

For the UFTP, all the short walls, bottom and lid are modeled to be 267 mm thick whereas the long walls are 272 mm thick. For simplicity, no gaps, joints, liners, crevices, or drain tubes are included in the model.

The UFTP is assumed to be fully loaded with each of the 48 module tubes within both fuel modules occupied by 2 bundles stored end to end. No empty module tubes are assumed. The module tubes are arranged in a 12-cm triangular pitch. The centres of the top and bottom rows of the 2 modules are separated by 2 lattice pitches (i.e., 24 cm). The rectangular structural frame holding the module tubes is omitted from the simulation model. Omission of this frame is a conservative assumption as the framework provides extra attenuation of photon and neutron particles emitting from the irradiated fuel bundles inside the UFTP.

A-1.1 UFTP Model with No Impact Limiter

Figures A-1-1 and A-1-2 show the Monte Carlo model of the UFTP containing 192 irradiated fuel bundles. Figure A-1-1 is the end-on sectional view of the UFTP showing the 2 groups of fuel bundles stored in the upper and lower storage modules.

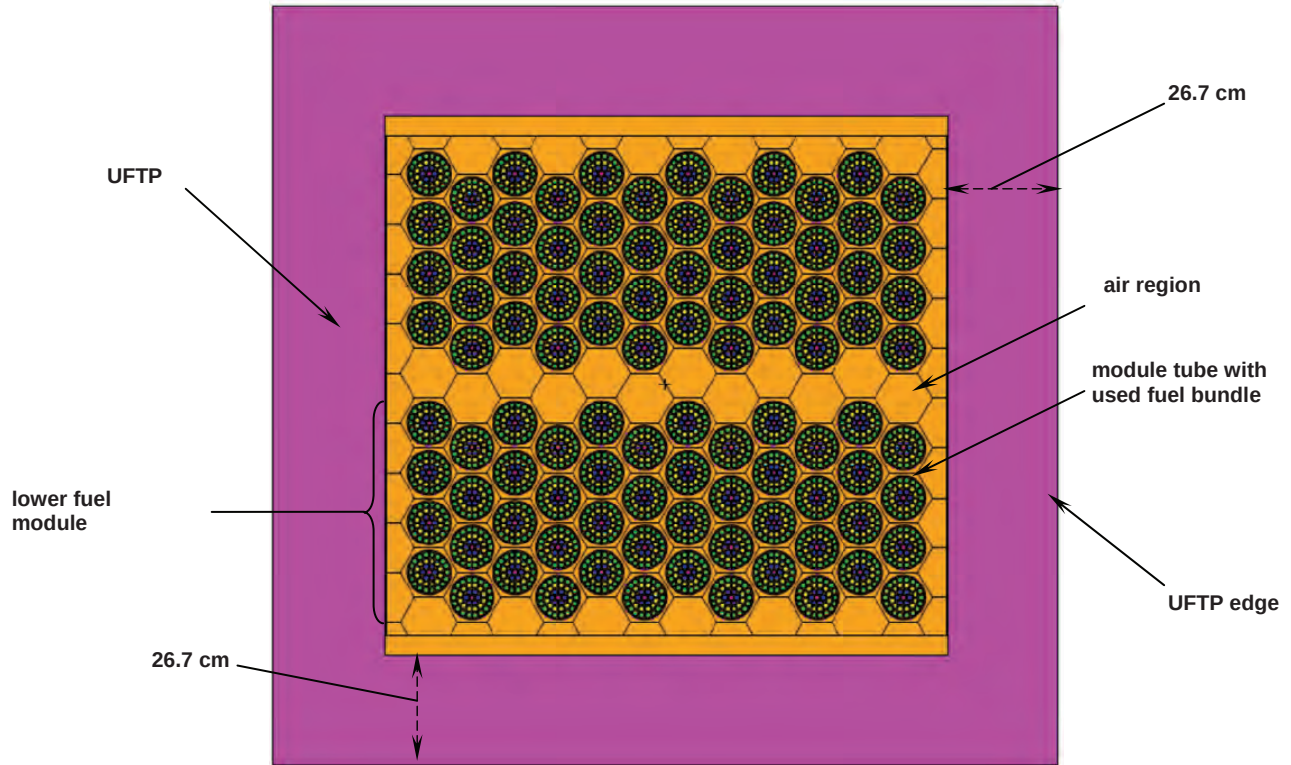


Figure A-1-1: Section View of the UFTP Model Showing Used Fuel in 2 Modules

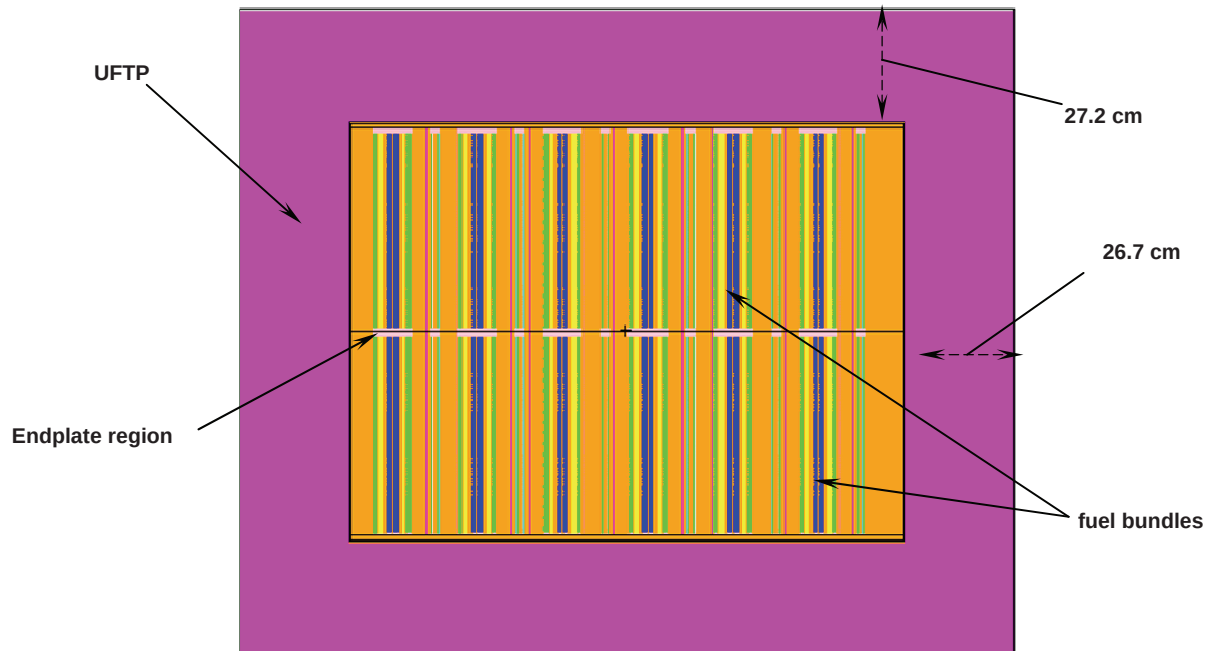


Figure A-1-2: Top View of the UFTP Model

A-1.2 Fuel Bundle and Module Tube

Each used fuel bundle is discretely modeled inside a module tube. This assembly is collectively defined as a hexagonal lattice with a lattice pitch of 12 cm (the centre to centre distance between fuel bundles) and a length of 49.53 cm. The lattice is a perfect hexagon with all 6 sides of equal length.

A pictorial representation of the Monte Carlo model of the fuel bundle is illustrated in Figure A-1-3. The fuel elements representing the separate fuel rings are all modelled the same as unirradiated natural uranium dioxide (see Section 3.2.5.3). The interfacing material the fuel elements and module tubes is modeled as air at room temperature (293°K). The module tube material is modelled as Type 304L stainless steel.

All bundles are modelled in the exact same azimuthal orientation inside the transfer tube as shown in Figure A-1-3. The module tube is concentric with the fuel-bundle axis with a finite gap separating the fuel elements in the outer fuel ring from the inner surface of the tube. The endcaps and endplate of the bundle are modelled as one homogenized region with a thickness of 7.15 mm and a radius of 50 mm.

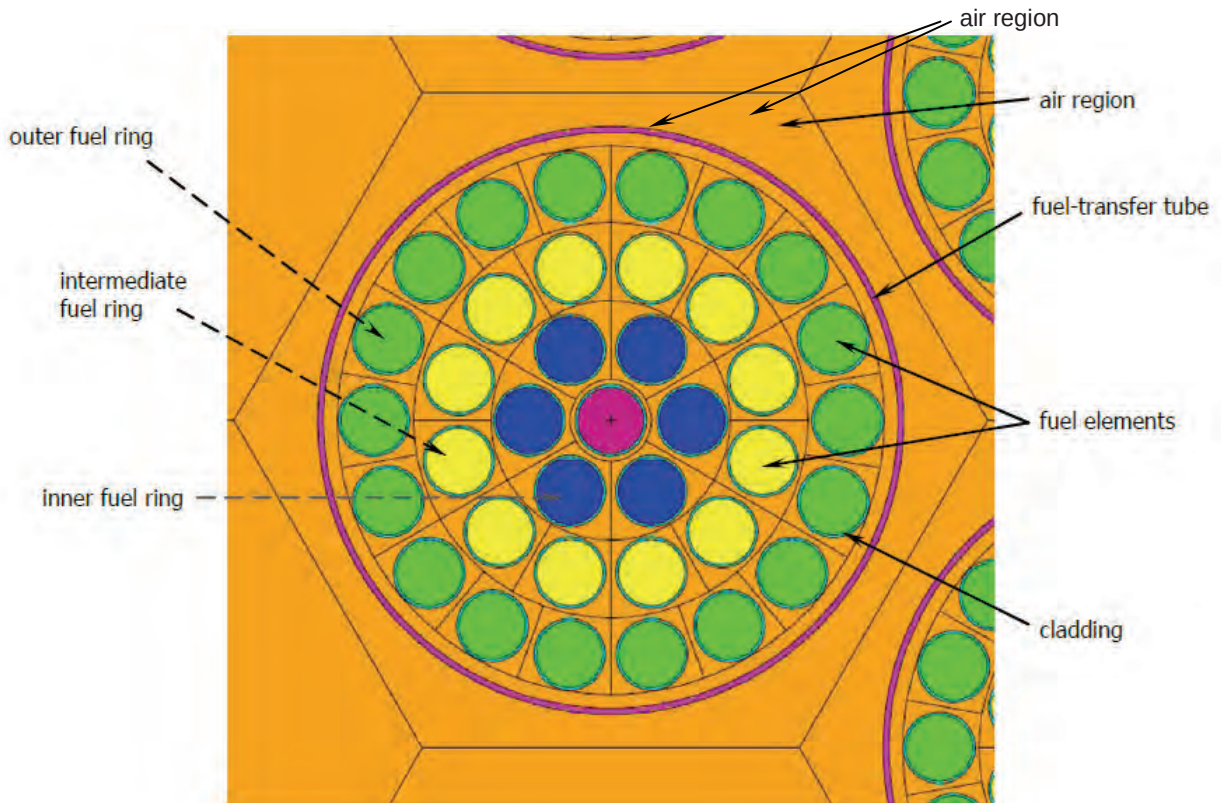


Figure A-1-3: Monte Carlo model of a 37-Element CANDU Fuel Bundle inside a Module Tube

A-1.3 Material Compositions

The UFTP, module and used fuel bundle are manufactured from various different materials as described in the applicable subsections of Section 3.2. These materials include uranium dioxide UO₂, zircaloy Zr-4, Type 304L stainless steel and air. The endplate regions of each fuel bundle are approximated as a homogenized mixture of air, end cap and endplate based on the zircaloy

mass in [A1]. The compositions of different materials and the endplate region used in the Monte Carlo model are listed in Table A-1-1.

The end-cap and endplate materials of the used fuel bundle are represented as a homogenized lower density Zr-4 material.

Table A-1-1: Material Compositions

Material	Element/ Nuclide	Weight Percent, wt-%	Material	Element	Weight Percent, wt-%
UO ₂ ($\rho=10.6 \text{ g/cm}^3$)	²³⁴ U	4.78×10^{-3}	ASTM 304L ($\rho =7.89 \text{ g/cm}^3$)	C	0.03
	²³⁵ U	6.29×10^{-1}		Cr	19
	²³⁸ U	8.78×10^1		Mn	2
	¹⁶ O	1.15×10^1		Ni	10
Zr-4 ($\rho =6.55 \text{ g/cm}^3$)	Sn	1.7×10^{-2}		N	0.1
	Fe	2.4×10^{-3}	Air ($\rho =0.0012 \text{ g/cm}^3$)	P	0.045
	Cr	1.3×10^{-3}		Si	1
	Ni	7.0×10^{-4}		S	0.03
	Zr	0.9786^3		Fe	67.795
Endplate ($\rho =2.32 \text{ g/cm}^3$)	Zr-4	reduced density		O ₂	23.2
				N ₂	75.47
				Ar	1.28

A-1.4 Source Definition

The dose-rate calculations are performed in a fixed-source mode. That is to say, the source activity profiles described in Appendix A-2 are inputs to MCNP. Based on these source profiles, particles are tracked from the fuel elements to the exterior of the UFTP model at different locations.

In the MCNP input files, source terms are explicitly defined as a volumetric source for each fuel element. The source term in each element is spatially constant in both axial and radial directions. Each element has a diameter of 12.3 mm and a length of 481 mm.

Note that while the neutron and gamma source terms are defined explicitly as fixed sources, the source for neutron capture gammas is generated from the neutron calculations through capture reactions along the neutron transport media. The spatial and energy profiles of the capture gammas are implicitly generated within the neutron transport calculations and are accounted separately from direct gamma radiation.

A-1.5 Cross Section Libraries

All nuclide cross sections used in the calculation are from the default MCNP cross-section libraries. The identification numbers used in the calculations are 42c, 50c, 60c, and 66c. All

³ Other trace impurities have been ignored in the calculation and are grouped as Zr.

material properties are assumed to be at 20°C (room temperature) with no additional temperature adjustment for neutron scattering.

In defining the material compositions, only elements with significant contents are included. Omission of trace materials does not have any impact on the neutron and photon transport process, hence the dose rates exterior of the UFTP are also unaffected.

A-1.6 Dose-Rate Conversions

With a nominal steel thickness no less than 26.7 cm, gamma shielding provided by the UFTP is so substantial that the expected gamma dose rates outside the UFTP due to decay gammas from irradiated fuel bundles are low. As a result, gamma dose rates are calculated using a partial deterministic approach with the use of the point-detector estimator coupled with the dose-rate conversion factors. The point detector estimator allows dose rates at distances far away from the UFTP to converge faster; although close to the UFTP surface the dose rates tend to fluctuate more because of higher scatter events.

All calculated fluxes at the dose receptors are multiplied by the neutron and photon fluence-to-dose-rate conversion coefficients from ICRP Publication 74 for neutrons (Table A-1-2) and photons (Table A-1-3). The coefficients used are for the antero-posterior phantom geometry⁴ which gives the highest dose rates.

Table A-1-2: Neutron Fluence-to-Dose-Rate Conversion Coefficients

Energy, MeV	$\mu\text{Sv.cm}^2.\text{s.h}^{-1}$	Energy, MeV	$\mu\text{Sv.cm}^2.\text{s.h}^{-1}$
1.00×10^{-9}	0.018864	1.00×10^{-2}	0.06588
1.00×10^{-8}	0.02358	5.00×10^{-2}	0.1386
2.50×10^{-8}	0.02736	1.00×10^{-1}	0.21528
1.00×10^{-7}	0.03582	3.00×10^{-1}	0.4788
5.00×10^{-7}	0.04608	5.00×10^{-1}	0.6768
1.00×10^{-6}	0.04968	7.00×10^{-1}	0.8316
5.00×10^{-6}	0.054	1	1.0152
1.00×10^{-5}	0.05436	1.2	1.116
5.00×10^{-5}	0.05328	2	1.3788
1.00×10^{-4}	0.05256	3	1.5552
5.00×10^{-4}	0.05112	4	1.6488
1.00×10^{-3}	0.05112	5	1.7064
5.00×10^{-3}	0.05652	6	1.7388

⁴ antero-posterior phantom geometry is where the radiation is incident directly face-on to a standing person's body.

Table A-1-3: Photon Fluence-to-Dose-Rate Conversion Coefficients

Energy, MeV	$\mu\text{Sv.cm}^2.\text{s.h}^{-1}$	Energy, MeV	$\mu\text{Sv.cm}^2.\text{s.h}^{-1}$
0.1	1.862×10^{-3}	1.5	2.205×10^{-2}
0.15	2.708×10^{-3}	2	2.696×10^{-2}
0.2	3.615×10^{-3}	3	3.559×10^{-2}
0.3	5.430×10^{-3}	4	4.326×10^{-2}
0.4	7.185×10^{-3}	5	5.040×10^{-2}
0.5	8.876×10^{-3}	6	5.755×10^{-2}
0.6	1.047×10^{-2}	8	7.171×10^{-2}
0.8	1.342×10^{-2}	10	8.554×10^{-2}
1	1.614×10^{-2}		

A-1.7 Road and Rail arrangement Geometries

The UFTP walls adjacent to the fuel bundle ends ('end-on') have an external dimension of 1881 mm, see Figure 4: UFTP Assembly in Section 3.2.3. The UFTP walls adjacent to the fuel bundle sides ('side-on') have an external dimension of 1566 mm.

Dose rates at the edge of the cask are calculated to determine the contributions from 2 UFTPs placing adjacent to each other for the rail transportation. For the rail transportation, the dose rates along the plane separating the 2 UFTPs can be estimated by doubling the edge dose rates of one UFTP to account for radiation coming from two UFTPs.

Geometry for road transport – single UFTP with its long side parallel to the direction of travel, and its short side (side with trunnions) in line with the ends of the truck.

Geometry for rail transport – two UFTPs per rail car. As in the truck case, its long side is parallel to the direction of travel, and its short side (side with trunnions) is in line with the ends of the train. Conservatively, no gap is assumed between the packages. The rail configuration is shown in Figure A-1-4.

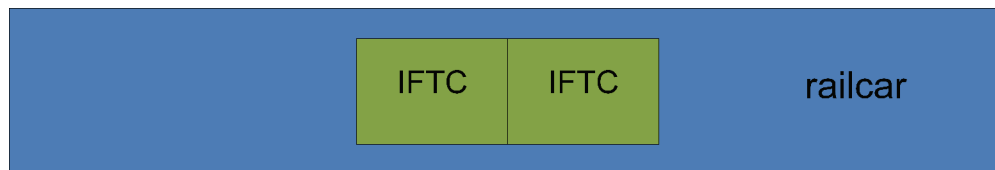


Figure A-1-4: Gamma Dose Rate Model Configuration for Railcar

Radiation is highest when one is directly facing the midplane of an UFTP. Dose rates at any distance away from the UFTP midplane or away from the UFTP wall surface will drop due to increase shield penetration and geometric attenuation respectively.

The regulatory limit of the UFTP is 0.1 mSv/h at 1 m. Radiation from an UFTP located behind another has to go through its own shield walls in addition to that of the UFTP in front plus the fuel inside. Attenuation provided by 2 UFTP shield walls is more than $1\text{E}+05$ for gammas and $4\text{E}+03$ for neutrons, see Appendix A-4. If it is assumed that all radiation coming from the UFTP located immediately behind another one is due to neutrons, the extra radiation caused by that UFTP is not expected to add more than 0.000025 mSv/h after the radiation has travelled past the cask in front using the 1 m regulatory dose-rate limit as the starting source. This anticipated dose-rate increase does not even account for the added attenuation provided by the fuel inside the UFTP and the distance factor.

As such, it is justifiable to exclude the contribution from all UFTP's that are located behind the first row in the calculations.

A-1.8 UFTP Model with Impact Limiter

Based on the bare UFTP model, the Impact Limiter and the weather cover are added to the model to assess the added neutron shielding provided by the 2 structures.

A schematic of the Impact Limiter is illustrated in Figure A-1-5. The Impact Limiter is made with redwood blocks encased inside a steel frame. The modelling assumptions of the Impact Limiter are listed as follows.

- Impact limiter is made of dry American redwood blocks
- Density of dry American redwood is 450 kg/m^3
- Redwood is assumed to be all cellulose with a chemical formula $(\text{C}_6\text{H}_{10}\text{O}_5)_n$
- No gap exists in the Impact Limiter
- Steel frame has a uniform thickness of 6 mm

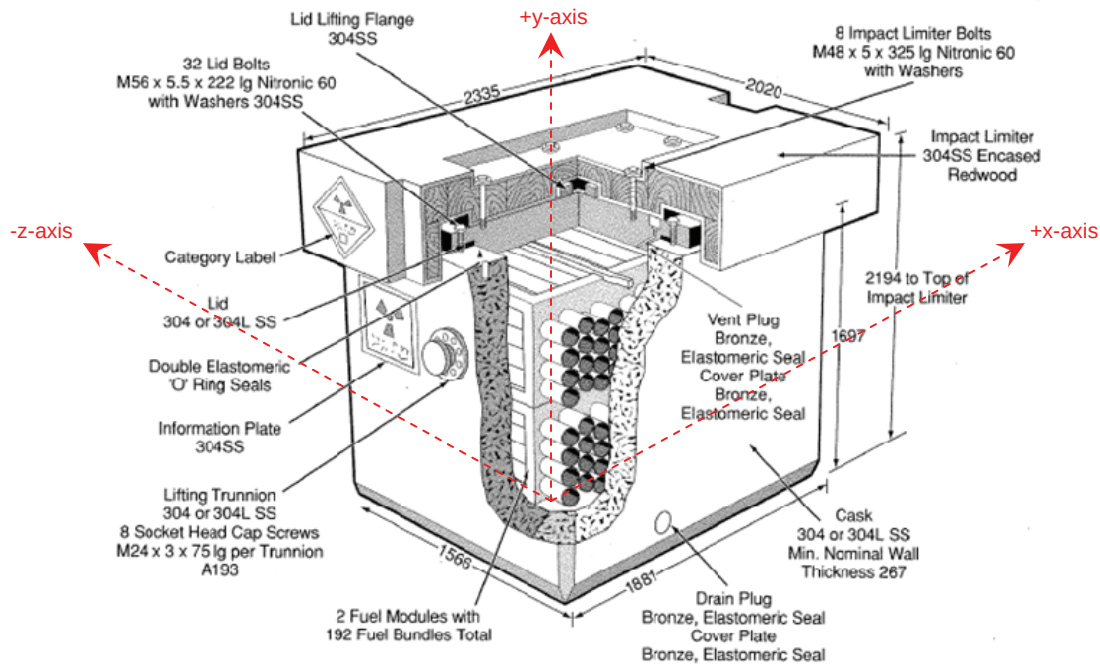


Figure A-1-5
UFTP – CANDU Used Fuel Transportation Package with Impact Limiter

Dimensions of the Impact Limiter are listed in Table A-1-4.

Table A-1-4: Dimensions of the Impact Limiter

Description		Dimensions, mm
Impact Limiter	Width (z-axis)	2020
	Depth (x-axis)	2335
Recessed Region	Width (z-axis)	1145
	Depth (x-axis)	830
Overall thickness including UFTP side overlap		640
Exterior height of UFTP	Without Impact Limiter	1824
	With Impact Limiter	2194
Steel liner thickness		6
Thickness along y-axis	General	370
	Recessed portion	225

A-1.9 Weather Cover Lined with Polyethylene

During road transportation the UFTP is covered by a weather shield. Whilst the frame of the weather shield does not provide any significant radiation shielding, there is a layer of polyethylene at the inner surface of the cover which can provide extra control of the neutron dose rates outside the UFTP.

The layer of high density polyethylene (HDPE) of the weather shield is modelled as the weather shield in the simulation model. The HDPE weather shield completely covers the UFTP including the impact limiter, analogous to the illustrations shown in Figures A-1-6 and A-1-7.

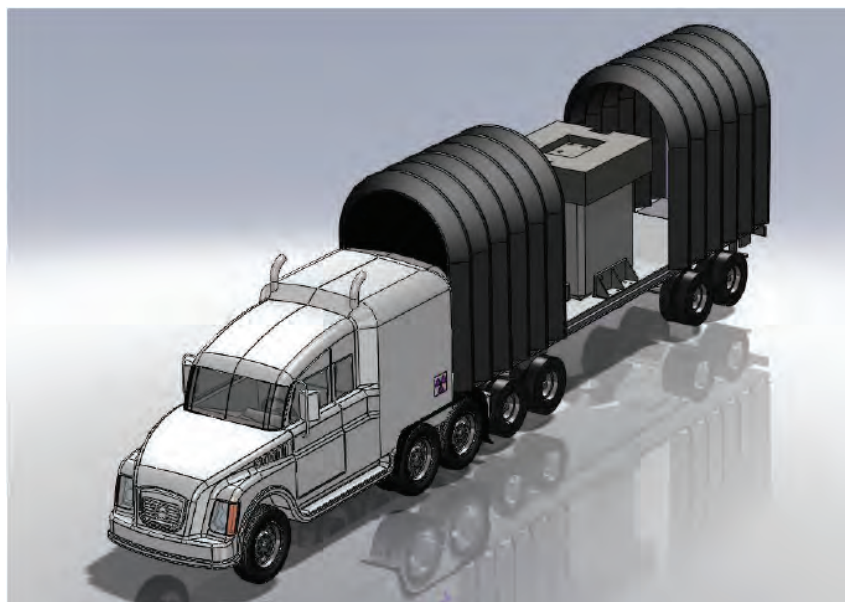


Figure A-1-6
Transportation Vehicle System with UFTP – Weather Cover Open

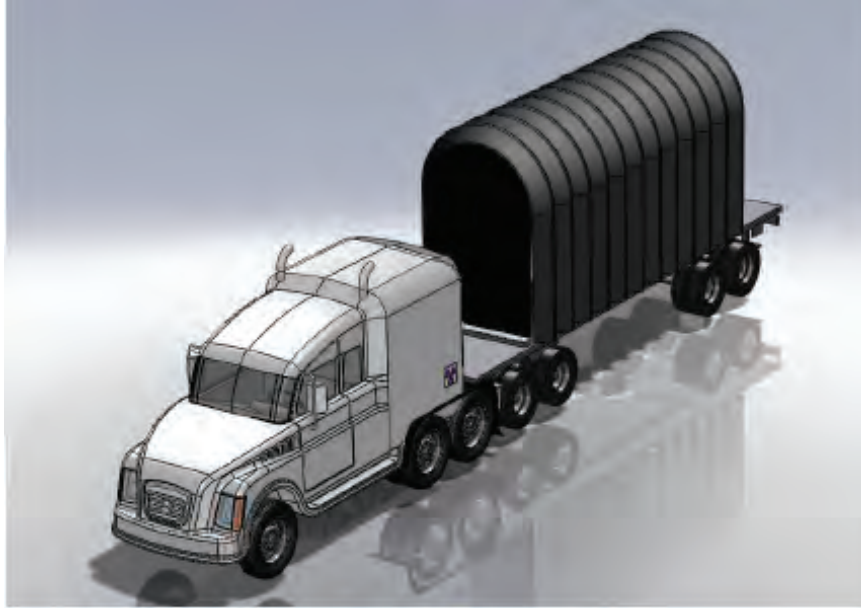


Figure A-1-7
Transportation Vehicle System with UFTP – Weather Cover Closed

The assumptions used in modelling the HDPE cover are as follows:

- HDPE is modeled as a rectangular cap over the UFTP with uniform thickness
- Thickness of the HDPE is 100 mm
- There is a 50 mm all around air gap between Impact Limiter and HDPE
- HDPE density range is 940-970 kg/m³
- HDPE density used in the model is 955 kg/m³
- Polyethylene chemical formula is (CH₂)_n

The simulation model of the impact limiter including the HDPE weather cover is illustrated in Figures A-1-8, A-1-9, and A-1-10. One can see that during road transportation, not only the weather cover (through the HDPE) can provide added neutron shielding; it also acts as a physical barrier to keep personnel at a certain distance from the UFTP surface.

The radioactive source terms used in the modified model are exactly the same as the ones used in the bare UFTP model which are detailed in Appendix A-2.

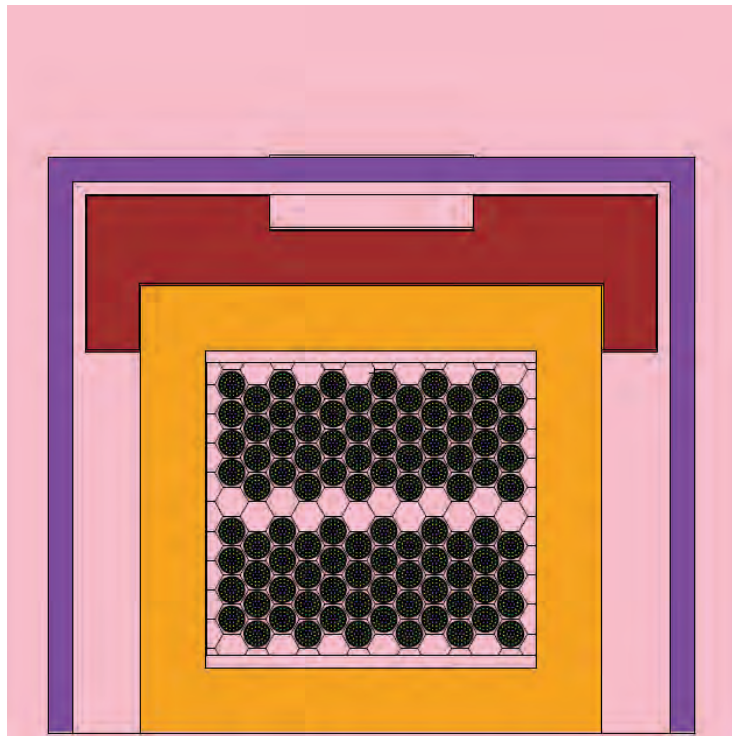


Figure A-1-8
Monte Carlo Model of the UFTP with Impact Limiter and HDPE Cover – End-on View

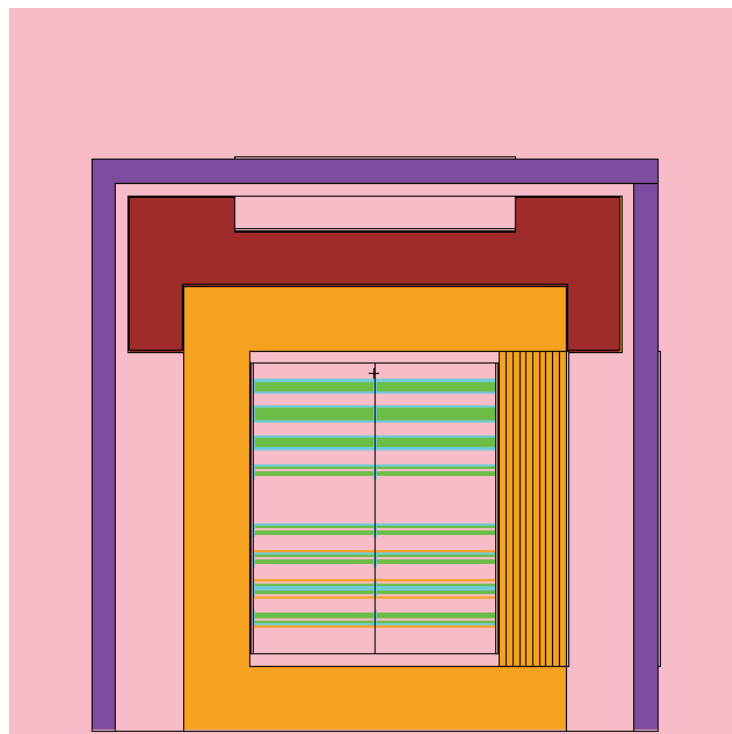


Figure A-1-9
Monte Carlo Model of the UFTP with Impact Limiter and HDPE Cover – Side-on View

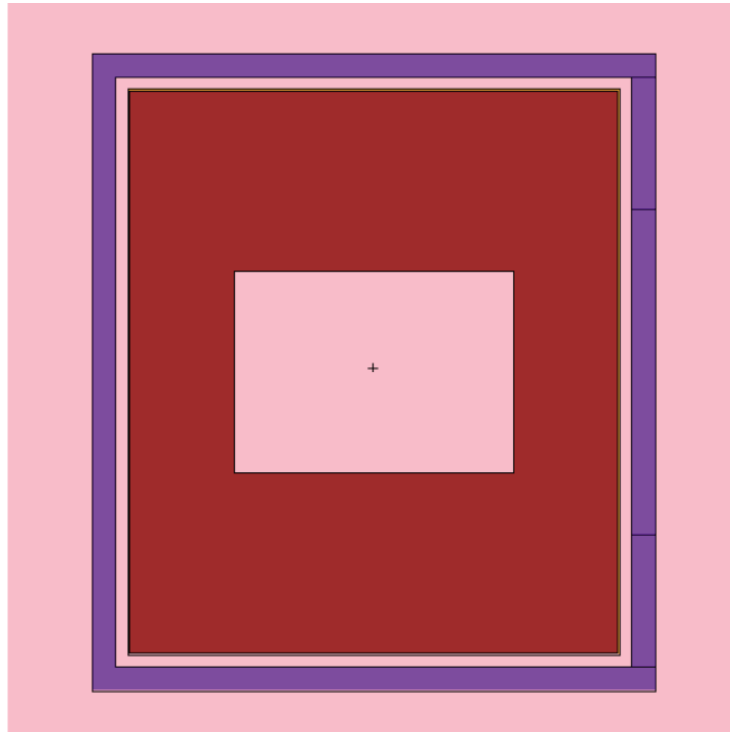


Figure A-1-10
MCNP Rendition of the UFTP, Impact Limiter, and HDPE – Plan View

A-2 Monte Carlo Model Inputs

A-2.1 Particle Release Spectra

The decay photon- and neutron-release spectra were taken from the OHN Report on radionuclide inventories of used nuclear fuel from OPG nuclear generating stations which includes Bruce A and Bruce B [A1]. Two irradiation burnup were considered in this report, i.e. 220 MWh/kgU and 280 MWh/kgU. The particle-release spectra 30 years after reactor shutdown for 2 fuel-bundle burnups are tabulated in Tables A-2-1 and A-2-2.

Table A-2-1: Photon Release Spectra for a 37-element CANDU Natural Uranium fuel bundle after 30 Years Decay for Discharge Burnup of 220 MWh/kgU and 280 MWh/kgU

Photon Release Spectrum at 30-Year Decay, γ/s per bundle		
Mean Energy, MeV	220 MWh/kgU	280 MWh/kgU
0.01	5.76E+12	6.95E+12
0.03	2.57E+12	3.15E+12
0.055	1.35E+12	1.65E+12
0.085	6.27E+11	7.51E+11
0.12	4.45E+11	5.39E+11
0.17	4.07E+11	4.86E+11
0.3	4.19E+11	5.00E+11
0.65	9.62E+12	1.22E+13
1.12	1.15E+11	1.52E+11
1.58	4.06E+09	5.25E+09
2	1.64E+08	1.94E+08
2.4	1.09E+05	1.44E+05
2.8	9.33E+06	1.41E+07
3.25	4.63E+03	1.04E+04
3.75	2.67E+03	6.03E+03
4.25	1.55E+03	3.49E+03
4.75	8.95E+02	2.02E+03
5.5	8.06E+02	1.82E+03

Table A-2-2: Neutron Release Spectra for a 37-element CANDU Natural Uranium fuel bundle after 30 Years Decay for Discharge Burnup of 220 MWh/kgU and 280 MWh/kgU

Neutron Release Spectrum at 30-Year Decay, neutrons/s per bundle		
Mean Energy, MeV	220 MWh/kgU	280 MWh/kgU
13.175	8.419E+00	1.962E+01
11.064	7.352E+01	1.713E+02
9.288	1.135E+02	2.644E+02
7.995	3.602E+02	8.394E+02
6.718	1.089E+03	2.538E+03
5.502	2.173E+03	5.065E+03
4.293	6.378E+03	1.416E+04
3.334	8.358E+03	1.642E+04
2.868	5.197E+03	9.613E+03
2.598	5.626E+03	1.058E+04
2.420	2.323E+03	4.427E+03
2.360	4.598E+02	8.792E+02
2.289	2.678E+03	5.119E+03
2.071	7.605E+03	1.477E+04
1.782	6.616E+03	1.339E+04
1.495	7.688E+03	1.626E+04
1.166	9.283E+03	2.046E+04
0.908	4.451E+03	1.005E+04
0.781	2.079E+03	4.739E+03
0.673	3.657E+03	8.394E+03
0.551	2.914E+03	6.704E+03
0.430	3.345E+03	7.730E+03
0.332	1.738E+03	4.016E+03
0.235	1.404E+01	1.865E+01
0.144	8.872E+00	1.179E+01
0.087	1.365E+00	1.814E+00

The bundle burnup of 220 MWh/kgU and 280 MWh/kgU represents the bounding burnup distribution for average and 95th percentile of all fuel-bundle discharge-burnup in OPG and Bruce Power reactors respectively. And for Darlington and Bruce B reactors, the 280 MWh/kgU represents the higher 99th percentile fuel-bundle discharge-burnup. Hence dose rates calculated using these 2 sets of spectra are considered bounding and conservative.

A-2.2 Photon Release Spectrum

At each burnup, the photon release spectrum of a fuel bundle is a result of 3 separate release contributions, viz. actinides, fission products, and light elements. Actinides and fission products are generated in the fuel due to direct fission yields and from neutron transmutations. For light elements, they represent the activation products of structural materials in the fuel bundle which include the bearing pads, spacer pads, end plates, end caps, and fuel cladding.

Over 98% of photon-energy release at 30 years decay is from fission products. And within fission products, over 90% is coming from ^{137}Cs . The principal contributors for both 220 MWh/kgU and 280 MWh/kgU fuel bundles are fission products which account for 98% of the total photon energy release.

A-2.3 Neutron Release Spectrum

The total neutron-release in a fuel bundle is a result of spontaneous fissions and (α, n) reactions in ^{17}O . Approximately $\frac{3}{4}$ of the energy is carried off by spontaneous neutrons.

Figure A-2-1 illustrates the neutron release spectra from spontaneous fission and ^{17}O (α, n) reactions. It also illustrates the relative change in spectrum between 220 MWh/kgU and 280 MWh/kgU. Neutron release from (α, n) reactions are higher at lower burnup but the reverse is true for the spontaneous fissions which has a higher release rate at higher burnup.

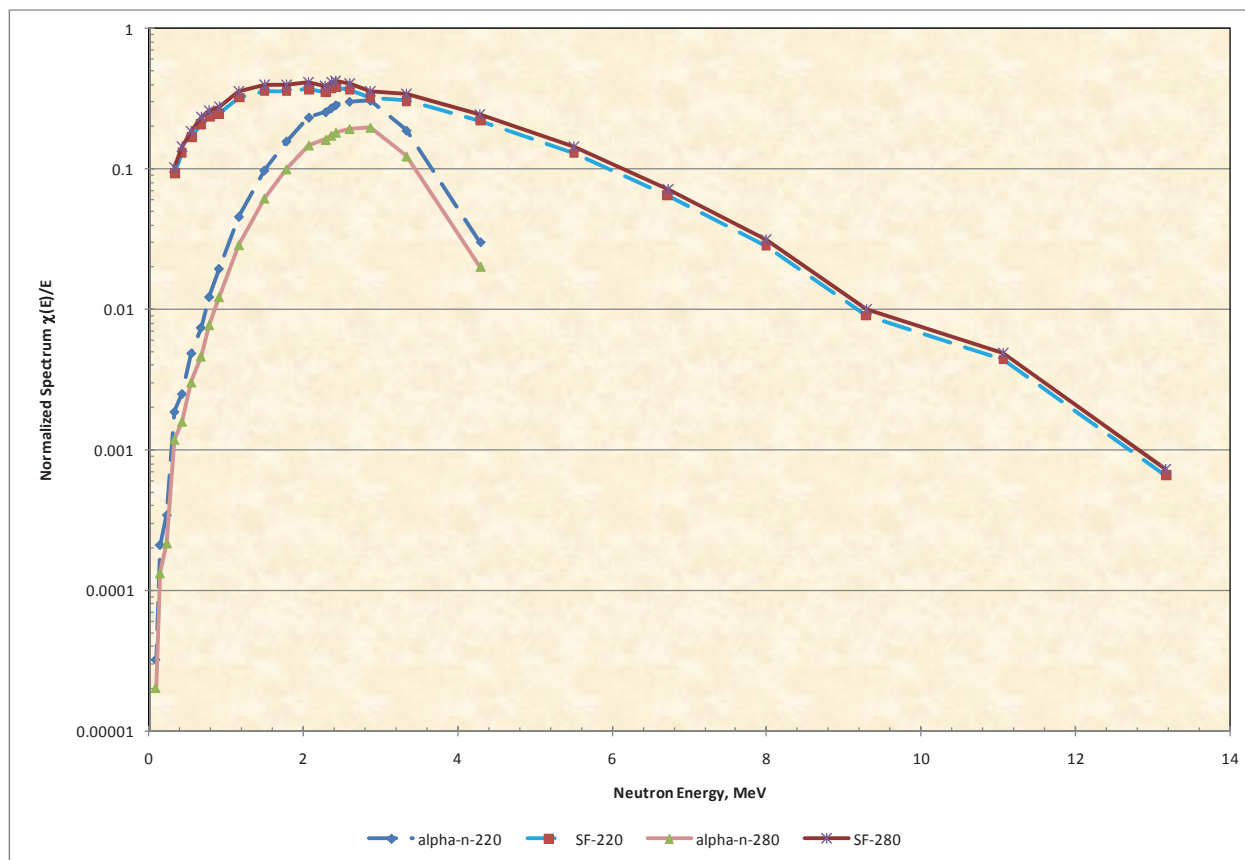


Figure A-2-1: Neutron Release Spectra from Spontaneous Fission and (α, n) Reactions

The integrated neutron release from spontaneous fissions is always higher than that from (α, n) reactions even at the maxima of the (α, n) -release spectrum. The relative decrease in neutrons generated by (α, n) reactions at higher burnup has a small impact to the overall increase in neutron production due to spontaneous fissions.

A-3 Detailed Dose Rate Tables – Monte Carlo Model Outputs

Dose rates listed in all the tables in the Appendix are calculated using the point-detector-tally option in MCNP. This tally option is ideal for obtaining dose rates at distances far away from the radiation source in a low scattering environment like air. However at tally locations where they are close to a scattering medium, the tally results tend to fluctuate significantly because there are significantly more scorings made at the tally locations from scattered particles with high importance and at close distance. The scoring is inversely proportional to the distance between the scoring location and the scatter location; therefore any scoring contributions that are due to scatter events close to the tally location will cause a large variance.

In the following tables, one will find the uncertainties of the gamma contact dose rates are higher than those at other locations. This is because gamma particles go through a lot of scattering events in the steel wall of the UFTP therefore causing large number of scores at close distance to the tally location. This makes the score fluctuates more leading to higher uncertainty. For every contact dose rate in the following tables, there is a footnote showing a near contact dose rate that has been averaged over the entire contact surface of the UFTP. This dose rate is calculated using a different tallying option in MCNP, the volume-averaged-tally option, which provides a much improved precision for the contact dose rates but is only representative to the average UFTP surface and not locally at a point. Because this tally option cannot be applied to dose locations far away from the UFTP, therefore it is only reported at contact with the UFTP.

Table A-3-1a: Dose Rates from UFTP at Receptor Location 1 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±7%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.0404	0.0208 ± 36% ⁵	1.79 × 10 ⁻⁴	0.061 ± 12%
0.3 m	0.0245	0.0125	1.10 × 10 ⁻⁴	0.037
1 m	0.00799 0.000445	0.00547	3.70 × 10 ⁻⁵	0.014 0.0060
2 m	0.00275 0.00017	0.00224	1.26 × 10 ⁻⁵	0.0050 0.0024
3 m	0.00136 0.000094	0.00114	6.10 × 10 ⁻⁶	0.0025 0.0012
10 m	0.00015 0.000018	0.000116	5.94 × 10 ⁻⁷	0.00027 0.00013
30 m	0.000018 0.000003	0.000012	6.51 × 10 ⁻⁸	0.000029 0.000015

Table A-3-1b: Dose Rates from UFTP at Receptor Location 1 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (±10%)	Capture Gamma (<±5%)	Total (<±5%)
Contact	0.0852	0.0168 ± 24% ⁶	3.62 × 10 ⁻⁴	0.10
0.3 m	0.0510	0.0153	2.29 × 10 ⁻⁴	0.067
1 m	0.0166 0.000445	0.00763	7.77 × 10 ⁻⁵	0.024 0.0082
2 m	0.00575 0.000169	0.00310	2.64 × 10 ⁻⁵	0.0089 0.0033
3 m	0.00283 0.000091	0.00150	1.28 × 10 ⁻⁶	0.0043 0.0016
10 m	0.000314 0.000018	0.000142	1.24 × 10 ⁻⁶	0.00046 0.00016
30 m	0.000037 0.000003	0.000014	1.36 × 10 ⁻⁷	0.000051 0.000018

Note: doses from package only are shown in plain text.
doses from package with weather cover are shown in **bold**.

⁵ Volume-averaged dose rate at the side-on surface of the UFTP is calculated to be 0.0114 mSv/h with an uncertainty of 4.7%.

⁶ Volume-averaged dose rate at the side-on surface of the UFTP is calculated to be 0.0143 mSv/h with an uncertainty of 4.7%.

Table A-3-2a: Dose Rates from UFTP at Receptor Location 2 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<10%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.00228	0.000027 ± 21%	9.68×10^{-6}	0.0023
0.3 m	0.00710	0.00134	3.32×10^{-5}	0.0085
1 m	0.00486 0.000247	0.00218	2.26×10^{-5}	0.0071 0.0025
2 m	0.00226 0.000135	0.00140	1.03×10^{-5}	0.0037 0.0015
3 m	0.00123 0.000085	0.000886	5.49×10^{-6}	0.0021 0.00098
10 m	0.000148 0.000018	0.000115	5.88×10^{-7}	0.00026 0.00013
30 m	0.000018 0.000003	0.000012	6.49×10^{-8}	0.000030 0.000015

Table A-3-2b: Dose Rates from UFTP at Receptor Location 2 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±5%)	Capture Gamma (<±5%)	Total (<±5%)
Contact	0.00486	0.00004 ± 17%	$2.14 \times 10^{-5} \pm 16\%$	0.0049
0.5 m	0.0148	0.00204 ± 12%	6.92×10^{-5}	0.017
1 m	0.0101 0.000228	0.00297	4.71×10^{-5}	0.013 0.0032
2 m	0.00470 0.000131	0.00191	2.15×10^{-5}	0.0066 0.0021
3 m	0.00255 0.000081	0.00126	1.15×10^{-5}	0.0038 0.0014
10 m	0.000308 0.000018	0.000146	1.23×10^{-6}	0.00046 0.00017
30 m	0.000037 0.000003	0.000016	1.36×10^{-7}	0.000052 0.000019

Note: doses from package only are shown in plain text.
doses from package with weather cover are shown in **bold**.

Table A-3-3a: Dose Rates from UFTP at Receptor Location 3 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±2%)	Gamma (<±5%)	Capture Gamma (<±5%)	Total (<±6%)
Contact	0.0354	0.0112 ± 23% ⁷	1.41 × 10 ⁻⁴	0.047
0.5 m	0.0214	0.0100	9.69 × 10 ⁻⁵	0.032
1 m	0.00739	0.00495	3.42 × 10 ⁻⁵	0.012
2 m	0.00266	0.00210	1.22 × 10 ⁻⁵	0.0048
3 m	0.00133	0.00115	5.99 × 10 ⁻⁶	0.0025
10 m	0.00015	0.000116	5.92 × 10 ⁻⁷	0.00027
30 m	0.000018	0.000012	6.50 × 10 ⁻⁸	0.000029

Table A-3-3b: Dose Rates from UFTP at Receptor Location 3 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±6%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.0753	0.0118 ± 23% ⁸	2.94 × 10 ⁻⁴	0.087
0.5 m	0.0447	0.0129	2.03 × 10 ⁻⁴	0.058
1 m	0.0154	0.00625	7.16 × 10 ⁻⁵	0.022
2 m	0.00554	0.00267	2.55 × 10 ⁻⁵	0.0082
3 m	0.00278	0.00141	1.25 × 10 ⁻⁵	0.0042
10 m	0.000311	0.00015	1.24 × 10 ⁻⁶	0.00046
30 m	0.000037	0.000016	1.36 × 10 ⁻⁷	0.000053

⁷ Volume-averaged dose rate at the side-on surface of the UFTP is calculated to be 0.0114 mSv/h with an uncertainty of 4.7%.

⁸ Volume-averaged dose rate at the side-on surface of the UFTP is calculated to be 0.0143 mSv/h with an uncertainty of 4.7%.

Table A-3-4a: Dose Rates from UFTP at Receptor Location 4 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±6%)	Gamma (<±9%)	Capture Gamma (<±5%)	Total (<±6%)
Contact	0.00215	0.000024 ± 22%	7.08×10^{-6}	0.0022
0.5 m	0.00627	0.00115	2.94×10^{-5}	0.0075
1 m	0.00454	0.00186	2.10×10^{-5}	0.0064
2 m	0.00219	0.00136	9.98×10^{-6}	0.0036
3 m	0.00121	0.000842	5.40×10^{-6}	0.0021
10 m	0.000148	0.000121	5.86×10^{-7}	0.00027
30 m	0.000018	0.000012	6.50×10^{-8}	0.000030

Table A-3-4b: Dose Rates from UFTP at Receptor Location 4 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±5%)	Gamma (<±4%)	Capture Gamma (<±5%)	Total (<±5%)
Contact	0.00415	0.000036 ± 23%	1.47×10^{-5}	0.0042
0.5 m	0.0131	0.00158 ± 11%	6.15×10^{-5}	0.015
1 m	0.00945	0.00255	4.4×10^{-5}	0.012
2 m	0.00456	0.00176	2.08×10^{-5}	0.0064
3 m	0.00251	0.00112	1.13×10^{-5}	0.0036
10 m	0.000308	0.000145	1.23×10^{-6}	0.00046
30 m	0.000037	0.000016	1.36×10^{-7}	0.000052

Table A-3-5a: Dose Rates from UFTP at Receptor Location 5 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±8%)	Capture Gamma (<±5%)	Total (<±6%)
Contact	0.0430	0.00366 ± 32% ⁹	1.93 × 10 ⁻⁴	0.047
0.5 m	0.0279	0.00737	1.29 × 10 ⁻⁴	0.035
1 m	0.0099 0.000539	0.00407	4.70 × 10 ⁻⁵	0.014 0.0047
2 m	0.00352 0.000206	0.00205 ± 15%	1.66 × 10 ⁻⁵	0.0056 0.0023
3 m	0.00174 0.000111	0.000965	8.10 × 10 ⁻⁶	0.0027 0.0011
10 m	0.000188 0.000019	0.000092	7.95 × 10 ⁻⁷	0.00028 0.00011
30 m	0.000021 0.000003	0.000009	8.69 × 10 ⁻⁸	0.000030 0.000013

Table A-3-5b: Dose Rates from UFTP at Receptor Location 5 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±2%)	Gamma (<±7%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.0885	0.0088 ± 32% ¹⁰	3.99 × 10 ⁻⁴	0.098
0.5 m	0.0579	0.0108	2.69 × 10 ⁻⁴	0.069
1 m	0.0205 0.000528	0.00550	9.85 × 10 ⁻⁵	0.026 0.0061
2 m	0.00728 0.000203	0.00236	3.46 × 10 ⁻⁵	0.0097 0.0026
3 m	0.00361 0.000109	0.00117	1.69 × 10 ⁻⁵	0.0048 0.0013
10 m	0.000388 0.000019	0.000117	1.66 × 10 ⁻⁶	0.00051 0.00014
30 m	0.000043 0.000003	0.000012	1.81 × 10 ⁻⁷	0.000055 0.000015

Note: doses from package only are shown in plain text.
doses from package with weather cover are shown in **bold**.

⁹ Volume-averaged dose rate at the end-on surface of the UFTP is calculated to be 0.0079 mSv/h with an uncertainty of 4.8%..

¹⁰ Volume-averaged dose rate at the end-on surface of the UFTP is calculated to be 0.0104 mSv/h with an uncertainty of 6.1%.

Table A-3-6a: Dose Rates from UFTP at Receptor Location 6 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±10%)	Capture Gamma (<±9%)	Total (<±4%)
Contact	0.00222	0.000015 ± 34%	$9.50 \times 10^{-6} \pm 13\%$	0.0022
0.5 m	0.00720	0.00107	3.43×10^{-5}	0.0083
1 m	0.00537 0.000238	0.00174	2.56×10^{-5}	0.0071 0.0020
2 m	0.00270 0.000147	0.00109	1.27×10^{-5}	0.0038 0.0013
3 m	0.00151 0.000094	0.000712	7.02×10^{-6}	0.0022 0.00081
10 m	0.000185 0.000019	0.000098	7.82×10^{-7}	0.00028 0.00012
30 m	0.000021 0.000003	0.000010	9.49×10^{-8}	0.000031 0.000013

Table A-3-6b: Dose Rates from UFTP at Receptor Location 6 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±5%)	Gamma (<±10%)	Capture Gamma (<±2%)	Total (<±5%)
Contact	0.00470	0.000017 ± 24%	$2.24 \times 10^{-5} \pm 21\%$	0.0047
0.5 m	0.0149	0.00110	7.16×10^{-5}	0.016
1 m	0.0111 0.000243	0.00189	5.36×10^{-5}	0.013 0.0023
2 m	0.00559 0.000148	0.00137	2.65×10^{-5}	0.0070 0.0016
3 m	0.00314 0.000095	0.000869	1.47×10^{-5}	0.0040 0.00098
10 m	0.000384 0.000019	0.000125	1.66×10^{-6}	0.00051 0.00015
30 m	0.000044 0.000003	0.000013	1.81×10^{-7}	0.000057 0.000016

Note: doses from package only are shown in plain text.
doses from package with weather cover are shown in **bold**.

Table A-3-7a: Dose Rates from UFTP at Receptor Location 7 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±6%)	Capture Gamma (<±3%)	Total (<±4%)
Contact	0.0377	0.00564 ± 25% ¹¹	1.59 × 10 ⁻⁴	0.044
0.5 m	0.0243	0.00726	1.14 × 10 ⁻⁴	0.032
1 m	0.00914	0.00367	4.36 × 10 ⁻⁵	0.013
2 m	0.00340	0.00162	1.60 × 10 ⁻⁵	0.0050
3 m	0.00171	0.000886	7.97 × 10 ⁻⁶	0.0026
10 m	0.000187	0.000094	7.94 × 10 ⁻⁷	0.00028
30 m	0.000021	0.000009	8.68 × 10 ⁻⁸	0.000031

Table A-3-7b: Dose Rates from UFTP at Receptor Location 7 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±7%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.0806	0.0115 ± 43% ¹²	3.39 × 10 ⁻⁴	0.092
0.5 m	0.0504	0.00934	2.37 × 10 ⁻⁴	0.060
1 m	0.0190	0.00480	9.08 × 10 ⁻⁵	0.024
2 m	0.00705	0.00213	3.35 × 10 ⁻⁵	0.0092
3 m	0.00354	0.00115	1.66 × 10 ⁻⁵	0.0047
10 m	0.000390	0.000127	1.66 × 10 ⁻⁶	0.00052
30 m	0.000043	0.000012	1.82 × 10 ⁻⁷	0.000056

¹¹ Volume-averaged dose rate at the end-on surface of the UFTP is calculated to be 0.0079 mSv/h with an uncertainty of 4.8%.

¹² Volume-averaged dose rate at the end-on surface of the UFTP is calculated to be 0.0104 mSv/h with an uncertainty of 6.1%.

Table A-3-8a: Dose Rates from UFTP at Receptor Location 8 with 220 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 220 MWh/kgU burnup)			
	Neutron (<±6%)	Gamma (<±9%)	Capture Gamma (<±5%)	Total (<64%)
Contact	0.00212	0.000013 ± 23%	6.89×10^{-6}	0.0021
0.5 m	0.00638	0.000825	3.04×10^{-5}	0.0072
1 m	0.00503	0.00149	2.39×10^{-5}	0.0065
2 m	0.00261	0.00104	1.23×10^{-5}	0.0037
3 m	0.00149	0.000672	6.88×10^{-6}	0.0022
10 m	0.000185	0.000095	7.80×10^{-7}	0.00028
30 m	0.000021	0.000010	8.65×10^{-8}	0.000031

Table A-3-8b: Dose Rates from UFTP at Receptor Location 8 with 280 MWh/kgU Burnup

Distance from Package	Dose Rate [mSv/h] (Used Fuel with 280 MWh/kgU burnup)			
	Neutron (<±3%)	Gamma (<±8%)	Capture Gamma (<±5%)	Total (<±4%)
Contact	0.00410	0.000015 ± 34%	1.43×10^{-5}	0.0041
0.5 m	0.0132	0.00111 ± 13%	6.35×10^{-5}	0.014
1 m	0.0104	0.00167	5.00×10^{-5}	0.012
2 m	0.00542	0.00126	2.57×10^{-5}	0.0067
3 m	0.00309	0.000895	1.44×10^{-5}	0.0040
10 m	0.000382	0.000118	1.63×10^{-6}	0.00050
30 m	0.000043	0.000013	1.81×10^{-7}	0.000056

A-4 Shielding Factors and Package Self-shielding

To assess the shield effectiveness of different materials outside the UFTP, one can use the attenuation coefficients of the material and apply it to the calculated dose rates at the appropriate receptor locations assuming radiation is following an exponential drop through the shield.

A-4.1 Neutrons

Majority of the dose rates outside the UFTP is coming from neutrons. The principal energy group of neutrons is below 1 MeV in the resonance region.

To estimate the shield effectiveness of a certain thickness of steel, one can use the neutron removal cross section of iron of 1.98 b/atom [A2] to obtain the mass attenuation coefficient (μ/ρ), where μ equals the product of the atom density and the removal cross section, and ρ is the material density. The attenuation provided by a steel slab of thickness t is simply $\exp(-\mu t)$ multiplied with a buildup factor. For fast neutrons in steel, a buildup factor of 2.5 can be used.

For example, to estimate the fast neutron attenuation through a 27.2 cm thick steel,

$$\mu = 1.98 \times \frac{7.9}{55.8} \times 0.6 = 0.168 \text{ cm}^{-1}$$

where 7.9 is the assumed density of steel, 55.8 is the atomic mass of iron, and 0.6 is the Avogadro's constant. The estimated attenuation is therefore 2.6×10^{-2} .

As for the shield effectiveness of neutrons going through concrete, one can estimate the drop in dose rates using the same approach but with the concrete macroscopic removal cross section of 0.089 cm^{-1} . Note that this application is not valid for thermal neutron attenuation.

A-4.2 Photons

The mass attenuation coefficients (μ/ρ) for photons are illustrated in Figure A-4-1. Radiation coming out of the UFTP is dominated by photons of energy 1 MeV and below. To estimate the drop in radiation provided by steel, one can apply (μ/ρ) of $0.06 \text{ cm}^2/\text{g}$ to $\exp(-\mu t)$ to estimate the attenuation factor. Since photons undergo significant number of scattering events when going through the shield, there is a buildup of secondary photons hence decreasing the attenuation factor. To properly estimate the shield effectiveness provided by a steel slab of thickness t , a buildup factor $B(t)$ has to be included, i.e. $B(t) \times \exp(-\mu t)$. In general for a steel slab with thickness below 15 cm, one can conservatively set $B (< 10 \text{ cm}) = 10$.

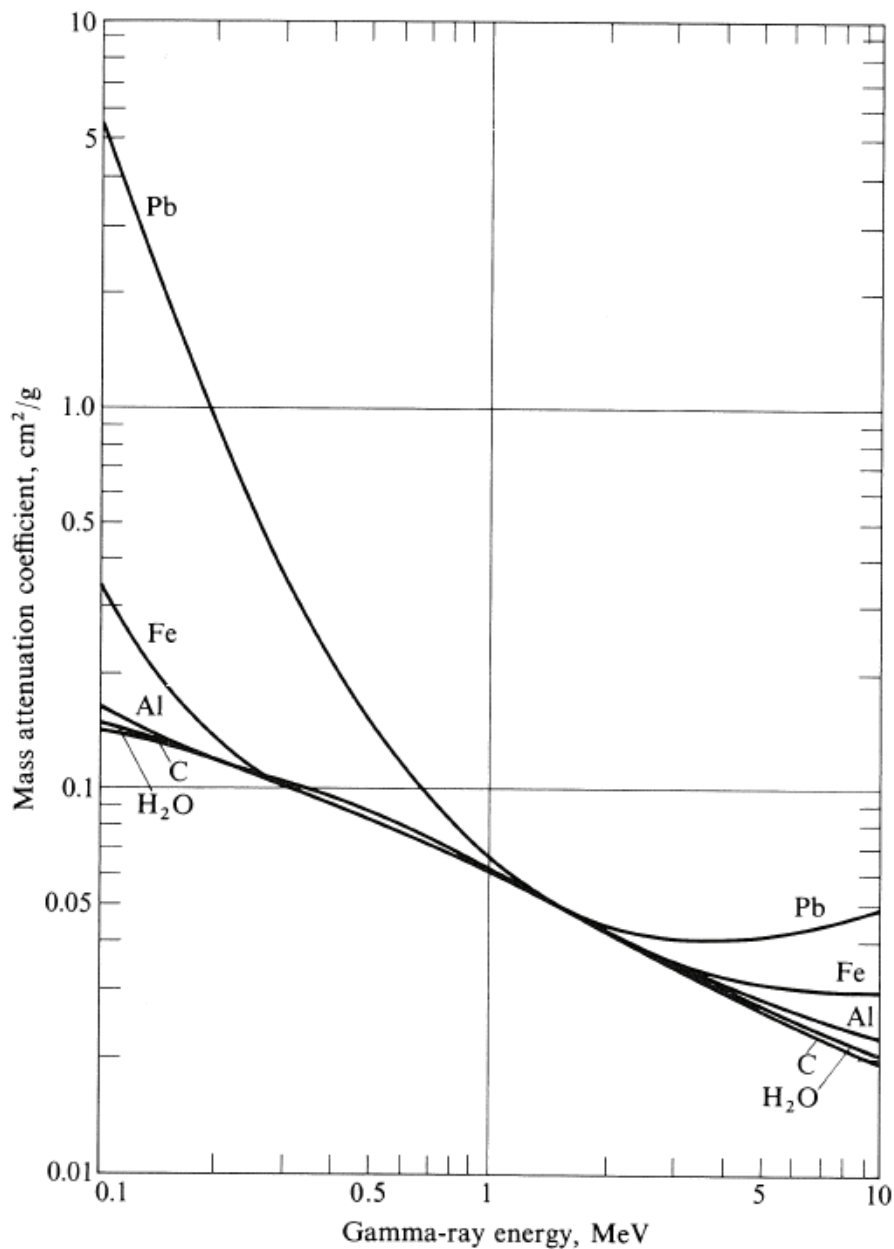


Figure A-4-1
Photon Mass Attenuation Coefficients of Several Elements [A3]

As for concrete, the mass attenuation coefficient is illustrated in Figure A-4-2. For example, photons at energy 1 MeV, (μ/ρ) is 0.06 cm²/g. And for concrete slab under 30 cm of thickness, a buildup factor of 10 can be conservatively applied when calculating the drop in dose rates outside the UFTP due to a certain concrete thickness.

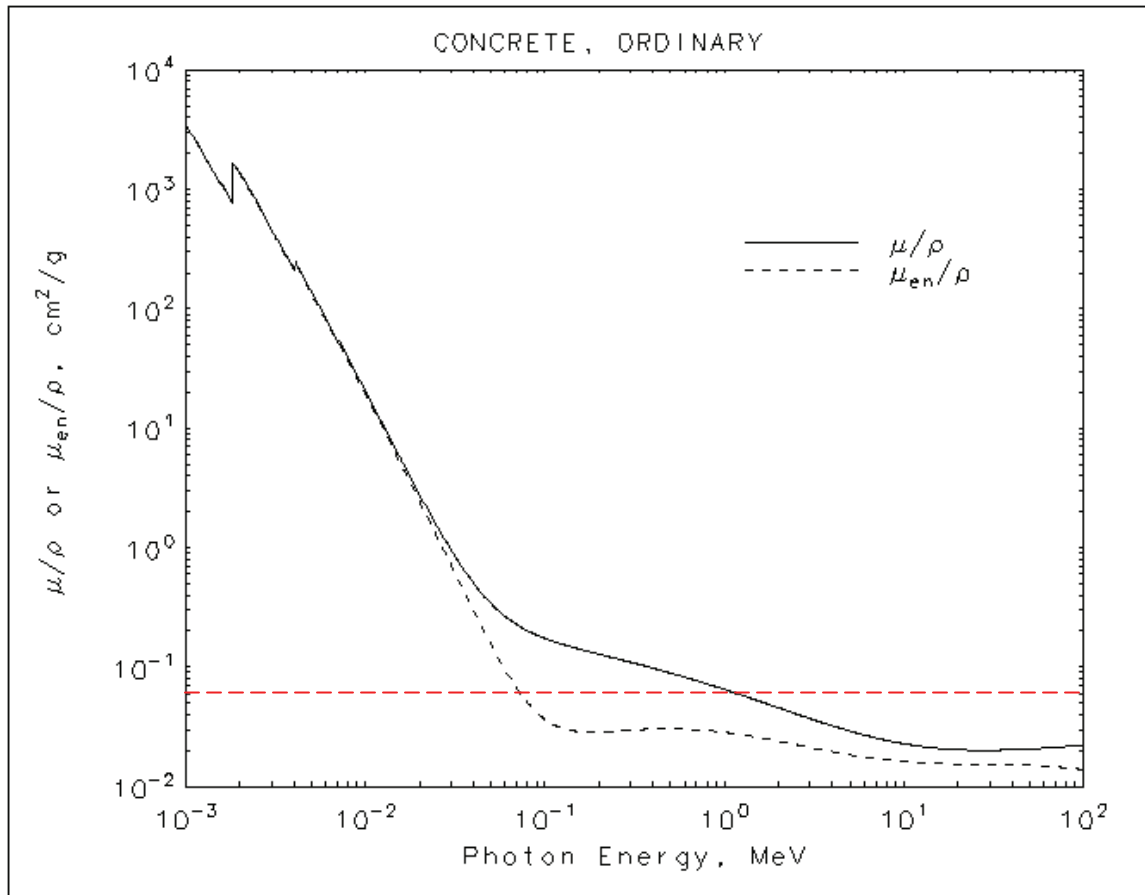


Figure A-4-2
Photon Mass Attenuation Coefficients in Concrete [A-10]

A-5 Rationale for Transportation Exposure Scenarios

The analysis in this report is generic, based on the assumptions described in this Appendix and does not describe either a specific route or geographic location. These assumptions were used to calculate a potential dose to an individual using the described distance and time parameters from a shipment operating under normal conditions. The information will assist NWMO to assess the general level of exposure to the public from the UFTP operating under normal transportation conditions and to highlight opportunities where NWMO can incorporate ALARA principles to further reduce the exposure to the public.

The analysis is not intended to provide an exhaustive analysis of any specific set of scenarios. Scenarios can be defined that could result in different dose levels than those presented in this report. However, a detailed assessment of transportation impact scenarios is premature until such factors as repository location, transportation mode and routes, population densities, transport package design, etc. are known. When these factors are established NWMO will prepare a corridor analysis to include dose assessments for those routes.

A-5.1 Road Transport Scenarios

Section 3.1.1.1 Individual along the Transport Route

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from external surface of cask	30 m is a conservative estimate of the right-of-way along a highway (A4). 30 m is assumed in the Ontario Hydro assessment (A5) and is the default setback distance in the RADTRAN code. (Note: RADTRAN 5 computer code is internationally considered the standard for transportation risk assessment modeling for radioactive materials.)
Exposure Time:	
Time for a tractor-trailer travelling at 24 km/h carrying 1 UFTC to pass by	24 km/h is the average vehicle speed assumed for transportation scenarios in reference A4.
Exposure Frequency:	
Individual is exposed to 620 shipments per year	620 shipments per year is the annual transport rate required to match the used fuel processing rate at the repository.

Section 3.1.1.2 a) Public Sharing Transport Route – Individual alongside UFTP

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 10 m from UFTP	10 m was chosen as the average distance between the individual and the UFTP during the entire length of the traffic jam. This is consistent with similar dose studies (A6). During the traffic jam, instances where the distance between the individual and the UFTP could be as close as 3 m (A3) could occur, however some relative motion between vehicles in the traffic jam was assumed.
Exposure Time:	
1 hour	The typical commute time by car in Canada's urban centres is approximately 30 minutes (A7). A gridlock scenario was assumed to be twice as long as the typical total time for a commute. Studies of similar scenarios (A6) have also estimated exposure time to be 30 minutes.
Exposure Frequency:	
Twice per year	Regulatory Guide G-208 <i>Transportation Security Plans for Category I, II or III Nuclear Material</i> stipulates that fixed schedules should be avoided. Variation in transport schedules and routes will tend to reduce the likelihood of repetitive exposure to a given individual. Therefore, 2 exposures over a one year period were assumed. Available sources (A6) suggest that exposure frequency to this type of scenario is a single event.

Section 3.1.1.2 b) Public Sharing Transport Route – Individual in front / behind UFTP

Assumptions:	Rationale:
Exposure Distance:	
Individual is located in vehicle 23 m in front or behind the UFTP on a trailer.	A typical semi trailer is approximately 16 m long. The UFTP is assumed to be positioned centrally on the trailer (external cask surface approximately 8 m from the end). Travelling at an average speed of 24 km/h (A4), the vehicle behind the trailer is assumed to be 2 seconds (13 m or approximately two car lengths) behind the trailer. The individual in the vehicle is assumed to be located approximately 2 m from the front of the vehicle. This results in an estimated exposure distance of 23 m.
Exposure Time:	
1 hour	The typical commute time by car in Canada's urban centres is approximately 30 minutes (A7). A gridlock scenario was assumed to be twice as long as the typical total time for a commute.
Exposure Frequency:	
6 times per year	Regulatory Guide G-208 <i>Transportation Security Plans for Category I, II or III Nuclear Material</i> stipulates that fixed schedules should be avoided. Variation in transport schedules and routes will tend to reduce the likelihood of repetitive exposure to a given individual. Therefore, 6 exposures over a one year period were assumed. Available sources (A6) suggest that exposure frequency for this type of scenario is a single event.

Section 3.1.1.3 Public near Rest Stop

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 10 m from UFTP on tractor-trailer	Studies of truck stop activities (A8) concluded that the average exposure distance in a suburban setting is 23 m and in a rural setting is 46 m. The default distance used in RADTRAN code is 30 m. 10 m was used as the estimate based on professional judgment and is within the above referenced cases.
Exposure Time:	
30 minutes	A total stop duration of 30 minutes is consistent with truck stop activity studies (A8).
Exposure Frequency:	
Twice per year	Regulatory Guide G-208 Transportation Security Plans for Category I, II or III Nuclear Material stipulates that fixed schedules should be avoided. Variation in transport schedules and routes will tend to reduce the likelihood of repetitive exposure to a given individual. 2 exposures per year were assumed, based on professional judgment.

Section 3.1.1.4 Public near Unplanned Stop

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from UFTP on tractor-trailer	An unplanned stop is assumed to be a mechanical breakdown, flat tire, or minor fender bender etc. where there is no impact on the UFTP. In this case, a 30 m perimeter would be established around the vehicle by transport, security and/or emergency response personnel (or in front and behind the vehicle if on the side of an active roadway). It is also conceivable that a residence is located 30 m away. 30 m is also the default distance for stops in RADTRAN.
Exposure Time:	
10 hours	In rural areas, it could conceivably take a lengthy period of time to obtain replacement parts, a replacement tractor or trailer and to bring in a portable crane. The 10 hour duration for such a stop was chosen based on professional judgment as to the time necessary to address the causes described and to return the vehicle to safe operation.
Exposure Frequency:	
Once per year	The vehicle fleet will be subject to a high level of inspections and maintenance. Industry experience of transportation programs of similar size has shown that the likelihood of unplanned stops is low. Available sources (A6) suggest that exposure frequency to this type of scenario in the same location as being a single event.

A-5.2 Rail Transport Scenarios

Section 3.1.2.1 Individual along the Transport Route

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from external surface of cask	30 m is a conservative estimate of the right-of-way along a rail line (A4). 30 m is assumed in the Ontario Hydro assessment (A5) and is the default setback distance in the RADTRAN code. Therefore, this distance was chosen for this analysis.
Exposure Time:	
Time for 1 rail shipment of 10 UFTCs travelling at 24 km/h to pass by	24 km/h is the average vehicle speed assumed for transportation scenarios in reference A4.
Exposure Frequency:	
Individual is exposed to 62 shipments per year	62 shipments per year is the annual transport rate required to match the used fuel processing rate at the repository.

Section 3.1.2.2 Public Sharing Transport Route – Individual alongside UFTP

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from external surface of cask	30 m is a conservative estimate of the distance between a rail line and a parallel running roadway. 30 m is used in the Ontario Hydro assessment (A5) and is the default setback distance in the RADTRAN code.
Exposure Time:	
Travelling alongside train at same speed as the train for 10 minutes	In various parts of the country, roads and rail lines run parallel to each other. Typically, trains and vehicles travelling alongside each other will not be travelling at the same rate of speed. A total exposure time of 10 minutes is consistent with rail activity studies (A6).
Exposure Frequency:	
Twice per year	Regulatory Guide G-208 <i>Transportation Security Plans for Category I, II or III Nuclear Material</i> stipulates that fixed schedules should be avoided. Variation in transport schedules will tend to reduce the likelihood of repetitive exposure to a given individual. Therefore, 2 exposures per year were assumed. Available sources (A6) suggest that exposure frequency to this type of scenario is a single event.

Section 3.1.2.3 Public near Signal Stop

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from external surface of cask	30 m is a conservative estimate of the distance between a rail line and a parallel running roadway. 30 m is used in the Ontario Hydro assessment (A5) and is the default setback distance in the RADTRAN code.
Exposure Time:	
Train stops at signal stop for 10 minutes	A total stop duration of 10 minutes is consistent with rail stop activity studies (A9).
Exposure Frequency:	
Individual is exposed to 62 shipments per year	62 shipments per year is the annual transport rate required to match the used fuel processing rate at the repository.

Section 3.1.2.4 Public near Unplanned Stop

Assumptions:	Rationale:
Exposure Distance:	
Individual is located 30 m from the train carrying UFTPs	An unplanned stop is assumed to be a mechanical breakdown or minor incident on the rail line where there is no impact on the UFTPs being transported by the train. In this case, it is assumed that a 30 m perimeter be set up around the train by rail, security and/or emergency response personnel. It is conceivable that a residence could be located 30 m away from the rail line. 30 m is the default distance for stops in RADTRAN.
Exposure Time:	
10 hours	In rural areas, it could conceivably take a lengthy period of time to obtain replacement parts or even a replacement engine or rail car, and/or a portable crane. The 10 hour duration for such a stop was chosen as a conservative estimate based on professional judgment for the time necessary to address the cause and return the shipment to safe operation.
Exposure Frequency:	
Once per year	The railcar fleet will be subject to a high level of inspection and maintenance reducing the likelihood of this type of scenario. Available sources (A6) suggest that exposure frequency to this type of scenario in the same location is a single event.

A-6 References

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APPENDIX B CALCULATION OF DOSE TO INDIVIDUAL ALONG TRANSPORT ROUTE

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This appendix provides an estimated exposure of a person standing at a fixed distance (l) normal to the transport-truck path going at a constant speed (v). The assumptions used in deriving the exposure are listed as follows.

1. The transport truck will not change its travelling speed.
2. The person is stationary and facing perpendicular to the transport-truck travel-path during the exposure period.
3. The person is at least 5 m away from the transport-truck travel-path, i.e. $L \geq 5$ m.
4. The person is located sufficiently far away from the UFTP therefore a point-source approximation can be applied, i.e. using the $1/r^2$ approximation to estimate dose rates at distance farther than 5 m.
5. The person is on the same elevation as the UFTP; no credit is given to the risen height of the truck bed.
6. There is no intervening structure between the person and the truck therefore no material attenuation other than geometric attenuation.

B-1 Integrated Dose at the Receptor

Assuming the person standing at P is at a fixed normal distance l from the travel path of the transport truck (see Figure B-1), the dose rate at location P, defined as $d(P)$, is inversely proportional to the distance between the UFTP and the receptor, i.e. distance r .

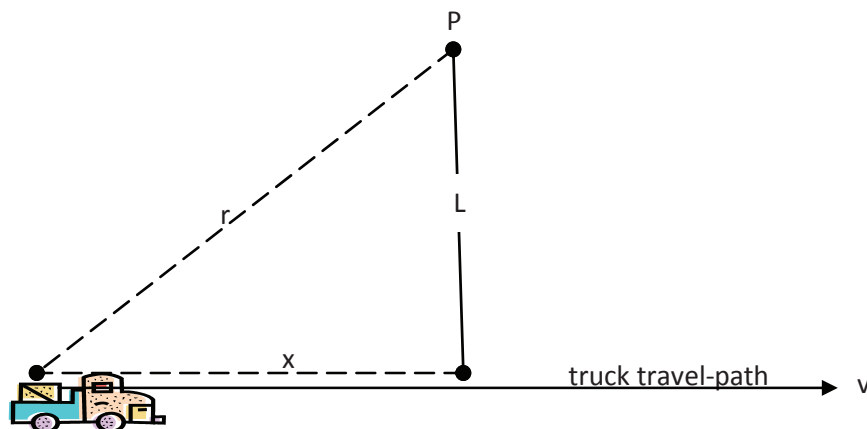


Figure B-1: Schematic of the Receptor Location P to the Travel Path

If we define S to be the end-on dose rate at h metres from the UFTP, then $d(r)$ at distance r can be formulated as follows.

$$d(r) = \frac{S \times h^2}{r^2} \quad (B1)$$

or

$$d(r) = \frac{S \times h^2}{(x^2 + L^2)} \quad (B2)$$

where x is the distance of the UFTP to the plane that is perpendicular to travel-path. Distance x at time t for a truck travelling at constant speed v is defined as

$$x = vt \quad (B3)$$

Therefore the total dose D at the receptor location P due to an approaching transport truck carrying 1 UFTP can be calculated by integrating equation B2.

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{(vt)^2 + L^2} dt \quad (B4)$$

Since

$$dx = v dt \quad (B5)$$

Therefore equation A4 becomes

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{x^2 + L^2} \frac{dx}{v} \quad (B6)$$

Completing the integration, the total dose D for a person standing at location P due to a non-stopping transport truck carrying one UFTP travelling at constant speed v at a non-varying distance L normal of the travel path is calculated by the following equation.

$$D = \frac{\pi S h^2}{3600 v L} \quad (B7)$$

The units for v and L are in m/s and m respectively. The units for D and S are in μSv and $\mu\text{Sv/h}$ respectively.

B-2 Dose-Rate Profile at the Receptor

Dose-rate profiles at the receptor location for different truck speeds are illustrated in Figure B-2. The profiles indicate the change in dose rates for the period in which the truck approaches the receptor from -200 m to the truck departs from the receptor at +200 m. As one would expect, the faster the truck travels, the shorter the exposure period hence a lower integrated dose D .

Presenting the information in a different format, Table B-1 shows the variation of the dose exposure as a function of truck speed and the separation distance L . Note that all doses are calculated with no credit given to any intervening structures between the receptor and the truck.

As there are 10 UFTPs on a rail shipment, the dose to an individual from a single shipment would be 10 times that of a road shipment for a particular distance between the individual and the path (rail line in the case of rail transport) as shown in Table B-2.

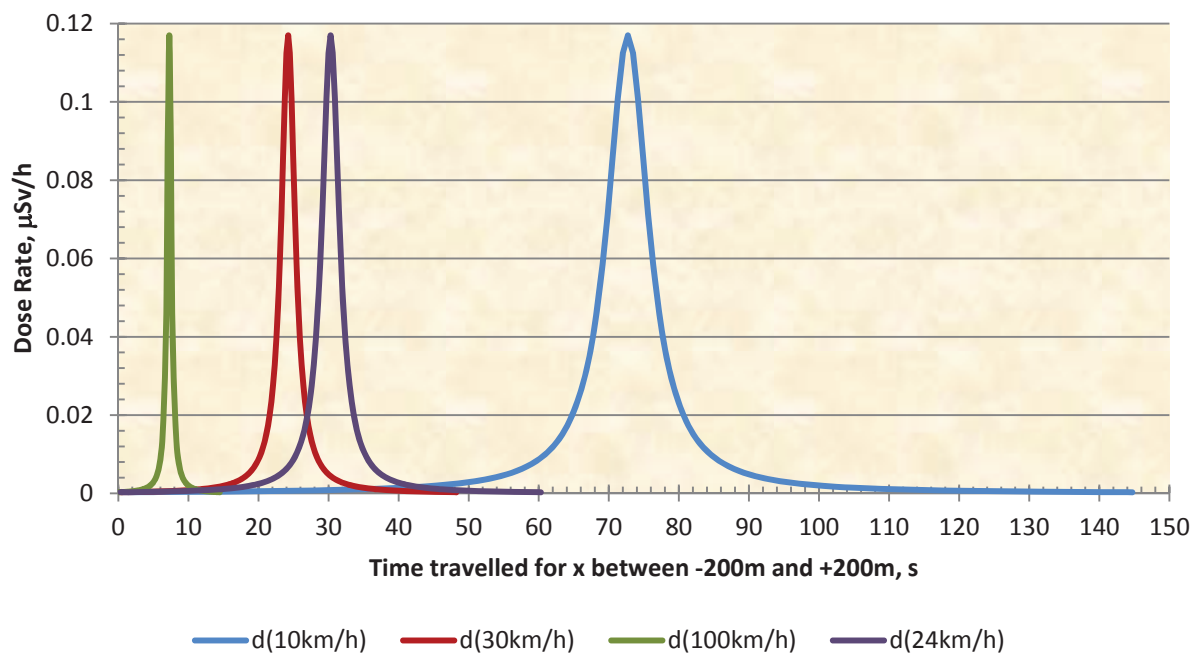


Figure B-2: Dose Rate at Receptor P over the Period the Truck Travels from -200 m to +200 m¹³

Table B-1: Integrated Dose at different Truck Speeds and Separating Distances

Distance L from Receptor to Truck Path, m	Integrated Dose D at Receptor Location P, mSv						
	5 km/h	10 km/h	24 km/h	30 km/h	50 km/h	80 km/h	100 km/h
3 m	2.0E-06	1.0E-06	4.2E-07	3.4E-07	2.0E-07	1.3E-07	1.0E-07
10 m	7.0E-07	3.5E-07	1.5E-07	1.2E-07	7.0E-08	4.4E-08	3.5E-08
30 m	2.5E-07	1.2E-07	5.1E-08	4.1E-08	2.5E-08	1.5E-08	1.2E-08
50 m	1.5E-07	7.4E-08	3.1E-08	2.5E-08	1.5E-08	9.2E-09	7.4E-09
100 m	7.4E-08	3.7E-08	1.5E-08	1.2E-08	7.4E-09	4.6E-09	3.7E-09

¹³ The dose-rate profiles are calculated based on the end-on dose rates at 30 m from the UFTP surface with a Weather Cover

Table B-2: Integrated Dose at different Railcar Speeds and Separating Distances

Distance L from Receptor to Rail Line, m	Integrated Dose D at Receptor Location P, mSv						
	5 km/h	10 km/h	24 km/h	30 km/h	50 km/h	80 km/h	100 km/h
3 m	2.0E-05	1.0E-05	4.2E-06	3.4E-06	2.0E-06	1.3E-06	1.0E-06
10 m	7.0E-06	3.5E-06	1.5E-06	1.2E-06	7.0E-07	4.4E-07	3.5E-07
30 m	2.5E-06	1.2E-06	5.1E-07	4.1E-07	2.5E-07	1.5E-07	1.2E-07
50 m	1.5E-06	7.4E-07	3.1E-07	2.5E-07	1.5E-07	9.2E-08	7.4E-08
100 m	7.4E-07	3.7E-07	1.5E-07	1.2E-07	7.4E-08	4.6E-08	3.7E-08

**APPENDIX C ASSESSMENT OF POTENTIAL DOSES AND FREQUENCIES FOR
SPECIFIED ACCIDENT CONDITIONS**

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C-1 Assessment of Potential Doses

In order to determine risks for releases corresponding to the hypothetical IAEA accident conditions scenario [C1], it is necessary to evaluate container damage, radioactivity emissions under the specified conditions and the likelihood of such as a stylized scenario taking place in real conditions.

The cask has been designed to maintain its integrity under both normal transportation and accident conditions as defined in the IAEA Transport Regulations [C1]. The UFTP design is such that under the defined conditions leakage will only be possible by permeation through the elastomer seals used between the faces of the cask lid and the cask body and at the vent and drain ports [C2].

The IAEA Transport Regulations specify tests for demonstrating ability of 'Type B' containers (the UFTP falls under this classification) to withstand defined accident conditions of transport. These conditions involve a drop from the height of 9m and exposure to a 30-minute fire at temperature of 800°C as well as a number of other requirements. As these are postulated testing conditions, the frequency of corresponding "accidents" cannot be assessed directly. In order to estimate such frequencies, a correlation has to be established with "real life" accident scenarios corresponding to the same radioactivity release rate.

The basis for determining an assumed release rate under the hypothetical conditions is the previous testing and assessment work on the cask, conducted by Ontario Hydro in 1980s and 90s [C2, C3]. Internationally, extensive testing on Type B containers was conducted by Sandia National Laboratories in the US and by the Central Electricity Generating Board in the UK, which includes both hypothetical testing conditions and severe accident scenarios, e.g. [C4]. This work demonstrated that certified cask designs sustain only very minor damage in testing conditions.

Impact and thermal response tests were carried out on an empty half-scale model of the UFTP cask, including a 9m drop and a one hour fire at 800°C temperature [C2]. No leakage was observed; and the main seal and the drain plug seal remained elastic at elevated temperatures. The drain cover plate seal remained intact in the seal groove but broke when it was lifted.

For the tested conditions corresponding to the IAEA Transport Regulations, although failure of the cask seal was not expected, it was assumed that there will be a leakage path available, for gases only, via permeation through the seal material, resulting in slow leakage of the gaseous radionuclides Krypton-85 (Kr-85) and Hydrogen-3 (H-3) [C2]. The same assumption was used as the basis for the current risk assessment for a hypothetical accident scenario. The UFTP reference inventory used in this assessment also includes radionuclides of elements that will or may be gaseous under the accident conditions considered, however due to their relative radioactivities and dose coefficients¹⁴, the dose contribution from these radionuclides would be several orders of magnitude less than from Kr-85 and H-3.

It was furthermore assumed that in order for this level of damage to occur, the cask would have to sustain an impact at a speed of over 50 kilometres per hour (corresponding to a free fall from a 9 metre height) against a hard rock surface in combination with a 30-minute fully engulfing, optically dense fire.

¹⁴ A dose coefficient is the dose that a person would receive from exposure through a specific exposure pathway from unit radioactivity of a radionuclide.

The Kr-85 and H-3 release rates for a UFTP containing used fuel of burnup 280 MWh/kgU aged 30 years out-of-reactor were calculated as follows.

Radioisotope concentrations were obtained from reference [C5] and used to determine the total Kr-85 and H-3 radioactivities in a UFTP:

Used fuel of burnup 280 MWh/kgU aged 30 years	Value	Units
U per bundle	19.2	kg
# of bundles	192	
Total U mass in UFTP	3686.4	kg
Zr per bundle	2.2	kg
Total Zr mass in UFTP	422.4	kg
Fuel Fission Product H-3 concentration	1.25E+09	Bq/kgU
Fuel Fission Product H-3 activity per UFTP	4.62E+12	Bq
Fuel Fission Product Kr-85 concentration	1.57E+10	Bq/kgU
Fuel Fission Product Kr-85 activity per UFTP	5.80E+13	Bq
Fuel Light Element Impurity H-3 concentration	2.00E+09	Bq/kgU
Fuel Light Element Impurity H-3 activity per UFTP	7.38E+12	Bq
Fuel Light Element Impurity Kr-85 concentration	1.59E+02	Bq/kgU
Fuel Light Element Impurity Kr-85 activity per UFTP	5.84E+05	Bq
Zircaloy Light Element Impurity H-3 concentration	3.10E+08	Bq/kgZr
Zircaloy Light Element Impurity H-3 activity per UFTP	1.31E+11	Bq
Zircaloy Light Element Impurity Kr-85 concentration	2.63E+01	Bq/kgZr
Zircaloy Light Element Impurity Kr-85 activity per UFTP	1.11E+04	Bq
Total H-3 activity per UFTP	1.21E+13	Bq
Total Kr-85 activity per UFTP	5.80E+13	Bq

Section 3.2 of Annex 6A of the UFTP Safety Analysis Report [C2] details the methodology used to calculate release rates. Updated free inventory fractions and grain boundary fractions for Kr-85 and H-3 were obtained from references [C5] and [C6] to determine the effective free inventories in the UFTP:

	H-3	Kr-85
Free inventory Fraction	0.0863	0.0863
Grain-boundary inventory fraction	0.041	0.041
Effective free inventory fraction (% of total)	12.73%	12.73%
Effective Free Inventory, S (Bq)	1.55E+12	7.39E+12

The leakage rate L (Ci/s) is given by the equation

$$L = P_k \times \frac{A}{d} \times \frac{S}{V} \times \frac{RT}{v}$$

where [C2]:

P_k = permeation coefficient = 2.60E-06 std cm³.cm/cm².s.atm

A = flow cross-sectional area = 548.76 cm²

d = flow path length = 1.08 cm

V = UFTP volume = 1.30E+06 cm³

R = ideal gas constant = 82.05746 cm³.atm/K.mol

T = temperature of fuel after fire = 414 K

v = volume occupied by 1 mole of gas at 296 K (standard temperature for leakage rate measurement) and one atmosphere (standard pressure) = 2.43E+04 cm³

Hence the leakage in eight hours (assumed maximum exposure time) and leakage rate per week is as follows:

	H-3	Kr-85
UFTP leakage rate [Bq/s]	2.22E+03	1.05E+04
UFTP leakage in 8 hours [Bq]	6.40E+07	3.08E+08
UFTP leakage per week [TBq/week]	0.00134	0.00635
Allowable leakage under Accident Conditions of Transport (IAEA TS-R-1 para 657) [TBq/week]	40	100

As can be seen, under accident conditions, the calculated leakage rate based on the assumed contents of the UFTP is 0.00134 TBq/week for H-3 and 0.00635 TBq/week for Kr-85; significantly less than the regulatory limits of 40 TBq/week for H-3 and 100TBq/week for Kr-85.

The following assumptions were made in determining doses to members of the public under the specified accident conditions in accordance with the methodology in the CSA Standard N288.2-M91 [C7]:

- Receptor is at ground level for ground level release along plume centre line with lower layer more stable than upper layer;
- Roughness length (z_0) is conservatively assumed to be 0.1 m (corresponding to open grassland, and hence no building wake);
- Pasquill stability category F and wind speed 2 m/s;
- Closest distance of receptor to UFTP is 30 m.

The Atmospheric Dilution Factor (ADF, s/m³) at the receptor point under these assumptions is given by

$$ADF = \frac{\Psi(x, y, z)}{Q} = \sqrt{\frac{2}{\pi}} \times \frac{1}{\sigma_z \mu x \left(\frac{2\pi}{16} \right)}$$

where

$\Psi(x, y, z)$ = time integrated activity concentration (Bq.s/m³) at receptor location (x,y,z)

Q = activity released to the atmosphere of the duration of the release (Bq)

μ = wind speed (m/s)

x = distance from source (m)

$$\sigma_z = g(x) F(z_0, x)$$

$$g(x) = \frac{a_1 x^{b_1}}{1 + c_1 x^{d_1}}$$

$$F(z_0, x) = \ln \left(\frac{c_1 x^{d_1}}{1 + c_2 x^{d_2}} \right)$$

when $z_0 \leq 0.1$ m

For $z_0 = 0.1$ m, the following values apply:

$$a_1 = 0.0638, a_2 = 1.36E-03, b_1 = 0.783, b_2 = 0.672, c_1 = 2.72, c_2 = 0, d_1 = 0, d_2 = 0$$

Dose from a specific exposure route for radionuclide a to receptor at location (x,y,z)
 $= \Psi(x,y,z) \times DC_a$

where

DC_a = dose coefficient for radionuclide a through a specific exposure route.

H-3 external dose coefficient for a semi-infinite cloud = $3.31E-19$ Sv per Bq.s.m⁻³ [C8]

Kr-85 external dose coefficient for a semi-infinite cloud = $1.19E-16$ Sv per Bq.s.m⁻³ [C8]

H-3 inhalation dose coefficient (includes skin absorption factor of 2) = $1.10E-14$ [C7]

As the cloud is not actually semi-infinite, Figure 8.2 of the CSA Standard provides a finite cloud correction for the external dose coefficients for a semi-infinite cloud based on the height of the release (ground level in this case) and the vertical standard deviation (σ_z). Note: as the figure does not go below $\sigma_z \sim 1.5$, for σ_z values below this a correction factor of 0.05 was conservatively assumed.

For receptor distances from the UFTP greater than 30 m, the UFTP will act as a point source for direct external dose. Hence direct external doses at distances greater than 30 m are calculated using the inverse square law.

The results are shown in Table C-1 and Figure C-1 for road transport accidents and Table C-2 and Figure C-2 for rail transport accidents. For rail transport, the same methodology as for road transport was used, with the exception that it is assumed that two UFTPs are affected by the accident, and hence the potential gaseous radioactive material release inventories are doubled.

The total accident dose in both road and rail transport is dominated by direct external exposure from the UFTP; doses from releases are negligible in comparison.

Table C-1: Potential Doses from Specified Road Transport Accident Conditions

Distance from UFTP to Receptor (m)	30	40	50	75	100	300	500	800
$g(x)$	0.90290	1.12783	1.33969	1.82968	2.28019	5.22328	7.60783	10.66985
$F(z_0, x)$	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063
σ_z (m)	0.90347	1.12855	1.34054	1.83084	2.28163	5.22658	7.61264	10.67659
ADF (s/m^3)	3.75E-02	2.25E-02	1.52E-02	7.40E-03	4.45E-03	6.48E-04	2.67E-04	1.19E-04
Finite cloud correction	0.05	0.05	0.05	0.062	0.071	0.16	0.22	0.28
H-3 $\psi(x, y, z)$ (Bq.s.m ⁻³)	2.40E+06	1.44E+06	9.70E+05	4.73E+05	2.85E+05	4.14E+04	1.71E+04	7.61E+03
Kr-85 $\psi(x, y, z)$ (Bq.s.m ⁻³)	1.13E+07	6.80E+06	4.58E+06	2.24E+06	1.35E+06	1.96E+05	8.07E+04	3.60E+04
Dose from H-3 (mSv)	2.64E-05	1.58E-05	1.07E-05	5.21E-06	3.13E-06	4.56E-07	1.88E-07	8.37E-08
Dose from Kr-85 (mSv)	6.74E-08	4.05E-08	2.73E-08	1.65E-08	1.14E-08	3.73E-09	2.11E-09	1.20E-09
External Dose from material remaining in UFTP (mSv)	4.56E-04	2.57E-04	1.64E-04	7.30E-05	4.10E-05	4.56E-06	1.64E-06	6.41E-07
Total Dose (mSv)	4.8E-04	2.7E-04	1.8E-04	7.8E-05	4.4E-05	5.0E-06	1.8E-06	7.3E-07

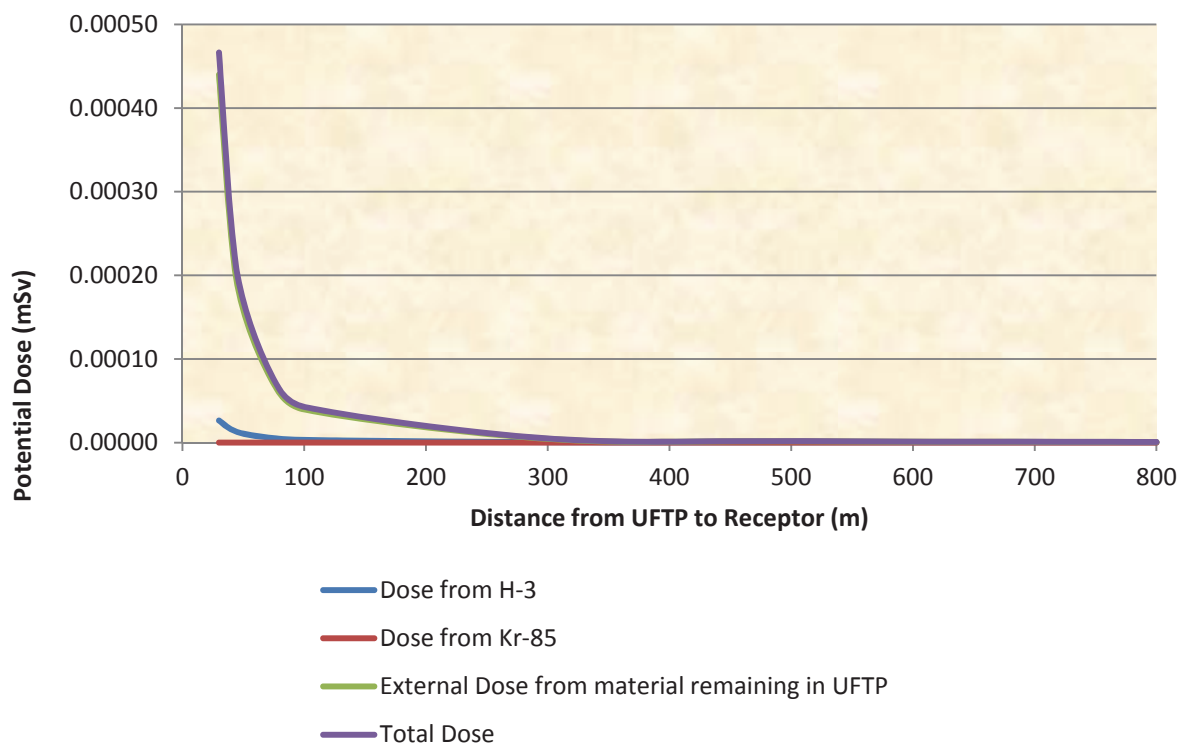


Figure C-1: Potential Doses from Specified Road Transport Accident Conditions

Table C-2: Potential Doses from Specified Rail Transport Accident Conditions

Distance from UFTP to Receptor (m)	30	40	50	75	100	300	500	800
$g(x)$	0.90290	1.12783	1.33969	1.82968	2.28019	5.22328	7.60783	10.66985
$F(z_0, x)$	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063	1.00063
σ_z (m)	0.90347	1.12855	1.34054	1.83084	2.28163	5.22658	7.61264	10.67659
ADF (s/m^3)	3.75E-02	2.25E-02	1.52E-02	7.40E-03	4.45E-03	6.48E-04	2.67E-04	1.19E-04
Finite cloud correction	0.05	0.05	0.05	0.062	0.071	0.16	0.22	0.28
H-3 $\psi(x, y, z)$ ($Bq \cdot s \cdot m^{-3}$)	4.80E+06	2.88E+06	1.94E+06	9.47E+05	5.70E+05	8.29E+04	3.41E+04	1.52E+04
Kr-85 $\psi(x, y, z)$ ($Bq \cdot s \cdot m^{-3}$)	2.27E+07	1.36E+07	9.16E+06	4.47E+06	2.69E+06	3.92E+05	1.61E+05	7.19E+04
Dose from H-3 (mSv)	5.27E-05	3.17E-05	2.13E-05	1.04E-05	6.27E-06	9.12E-07	3.76E-07	1.67E-07
Dose from Kr-85 (mSv)	1.35E-07	8.10E-08	5.45E-08	3.30E-08	2.27E-08	7.46E-09	4.22E-09	2.40E-09
External Dose from material remaining in UFTP (mSv)	9.12E-04	5.13E-04	3.28E-04	1.46E-04	8.21E-05	9.12E-06	3.28E-06	1.28E-06
Total Dose (mSv)	9.7E-04	5.5E-04	3.5E-04	1.6E-04	8.8E-05	1.0E-05	3.7E-06	1.5E-06

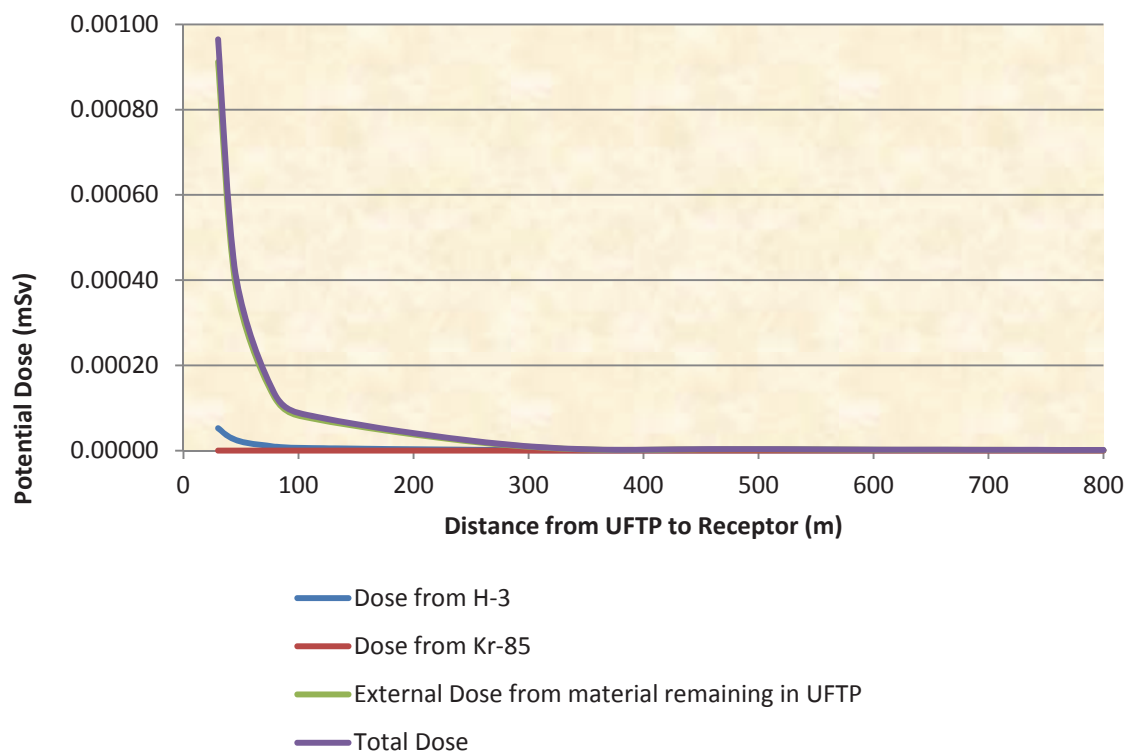


Figure C-2: Potential Doses from Specified Rail Transport Accident Conditions

The potential for loss of shielding from an accident resulting in radiation levels at 1 m from the surface of the UFTP exceeding the IAEA Transport Regulations criterion of 10 mSv/h [C1] was also investigated. The UFTP Safety Analysis Report [C2] concluded through drop tests that the maximum loss of shielding under the conditions specified [C1] would be approximately 75% of that which would be required to exceed the limit, and hence is compliant with the requirement. The reference UFTP inventory used in the UFTP Safety Analysis Report has used fuel aged 10 years out of reactor, whereas the current assessment uses a reference UFTP inventory with used fuel aged 30 years out of reactor. The difference in age of used fuel out of reactor results in lower radiation levels, and hence will also be compliant with the requirement.

C-2 Evaluation of Frequencies

For each mode of transport, annual frequency of accident conditions described in Section C-1 can be estimated as follows:

$$F_{\text{hypothetical}} = F_{\text{accident rate}} \times P_{\text{hard rock impact}} \times P_{\text{severe fire}}$$

Where $F_{\text{accident rate}}$ is the frequency of vehicles carrying the UFTP being involved in an accident, $P_{\text{hard rock impact}}$ is the conditional probability that following an accident a container will be subjected to an impact against hard rock at the speed of at least 50 kilometres per hour and $P_{\text{severe fire}}$ is the conditional probability of the container being immersed in a 30-minute engulfing, optically dense fire.

The basis of the calculations for each mode of transport is described below.

C-2.1 Road Transportation

The following parameters were used in determining annual frequency of a hypothetical accident scenario for road accidents:

- $F_{\text{accident rate}} = 1.72\text{E-}06$ accidents/vehicle-km. This is the average value for road transport accidents in Ontario on the basis of the Ontario Road Safety Annual Report 2009 [C10].
- $P_{\text{hard rock impact}} = 0.0016$. This is calculated as combined conditional probability of all sequences of events resulting in impact against hard rock as presented in the Modified Modal Study truck accident event tree [C10], including the following sequences:
 - Collision/On road fixed object/Bridge railing/Hard rock;
 - Non-collision/Off road/Into Slope/Hard rock;
 - Non-collision/Off road/Over Embankment/Hard rock.
- It was conservatively assumed that all impacts occur at speeds at or above 50 kilometres per hour; hence the conditional probability corresponding to this factor is equal to 1.
- $P_{\text{severe fire}} = P_{\text{fire}} \times P_{\text{high temperature}} \times P_{\text{engulfing}}$

P_{fire} is the conditional probability of traffic accidents resulting in a fire. For fires involving transportation of dangerous goods by road, it was shown on the basis of Transport Canada data that $P_{\text{fire}} = 0.06$ [C11].

Electrometric seal begins to leak at temperatures in excess of 350 °C [C10]. However, higher temperatures are required to cause significant fuel damage, here assumed to be consistent with the hypothetical accident scenario specified in the IAEA Transport Regulations [C1]. In practice, most fires result in temperatures in excess of 750 °C [C12], only 50 °C below the postulated condition. Hence $P_{\text{high temperature}}$ is conservatively taken as 1.

Fires have to be large enough, and be sustained for long enough, to prevent loss of energy from the cask to the atmosphere. This is required to cause internal elevation of temperature resulting in a significant damage to fuel sheath [C10]. In fact, the fire has to be “optically dense”, i.e. its dimensions must exceed dimensions of the cask by several meters.

It has been estimated that half of all road fires are engulfing; hence $P_{\text{engulfing}} = 0.5$ [C13].

Thus for transportation by road, $F_{\text{hypothetical}} = 1.72\text{E-}06 \times 0.0016 \times 1 \times 0.06 \times 1 \times 0.5 = 8.26\text{E-}11$ accidents/vehicle-km.

C-2.2 Rail Transportation

The following parameters were used in determining annual frequency of a hypothetical accident scenario for rail accidents:

- For Canada, the rail accident rate ($F_{\text{accident rate}}$) is $8.82\text{E-}06$ accidents/vehicle-km [C14].
- $P_{\text{hard rock impact}} = 0.00036$. This is calculated as combined conditional probability of all sequences of events resulting in impact against hard rock as presented in the Modified Modal Study train accident event tree [C10], including the following sequences:
 - All Derailments/Over Bridge/Hard Rock
 - All Derailments/Over Embankment/Hard Rock
 - All Derailments/Into Slope/Hard Rock
- It was conservatively assumed that all impacts occur at speeds at or above 50 kilometres per hour; hence the conditional probability corresponding to this factor is equal to 1.
- A recent US study analyzed statistical data on railway transportation of hazardous material. It was concluded that the frequency of accidents per freight kilometre was $1.8\text{E-}06$, however only $1.9\text{E-}09$ for the accidents that resulted in severe fires [C155]. It can be inferred that the conditional probability $P_{\text{severe fire}}$ is therefore one in a thousand (0.001).

Thus for transportation by rail, $F_{\text{hypothetical}} = 8.82\text{E-}06 \times 0.00036 \times 1 \times 0.001 = 3.2\text{E-}12$ accidents/vehicle-km.

C-3 References

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Appendix K – Transport of Radioactive Materials in Canada in 2021 and 2022

TRANSPORT OF RADIOACTIVE MATERIALS IN CANADA IN 2021 AND 2022

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ABSTRACT

Canada is one of the world's leading producers, users and exporters of nuclear fuel cycle products and radioisotopes for industrial, medical and research purposes. Based upon a survey conducted by the International Atomic Energy Agency (IAEA) in the early 1980s, Canada was the second largest shipper of radioactive material (RAM) packages of all reporting countries. According to a survey done in 1992 by the Canadian Nuclear Safety Commission (CNSC) (then known as the Atomic Energy Control Board), over one million packages of RAM were exported, imported or shipped within Canada annually. A new study was recently conducted to update these data and to have a better understanding of the number of RAM shipments each year in Canada. This study will provide the public with objective technical and regulatory information and help to better regulate the industry and manage risk.

The study involved collecting data on RAM shipments in Canada in 2021 and 2022. The study was broken down into the following six sectors: industrial, medical, nuclear fuel cycle, commercial, academic and research, and other. Approximately 1,500 CNSC licensees were contacted, encompassing over 2,100 CNSC licences. The survey collected data on:

- All types of CNSC regulated RAM transport packages, i.e., excepted packages, Type IP-1, Type IP-2, Type IP-3, Type A, Type B, Type H and fissile material packages.
- Modes of transport used for shipment of these packages.
- Number of packages shipped each year.
- Activity (TBq) of the RAM contents shipped each year.

EXECUTIVE SUMMARY

World-wide, more than 20 million packages of radioactive material are transported each year by road, rail, air or sea. It is estimated that in Canada, on average, there are approximately 760,000 RAM shipments each year, involving 900,000 packages with a total activity of about 1,700,000 TBq. Most of these shipments are transported, at least in part, by road. The largest number of shipments are made by portable gauge users in the industrial sector, accounting for almost 49% of total shipments. The second largest are in the commercial sector, accounting for almost 24% of total shipments, and are responsible for the majority of radiopharmaceutical shipments to hospitals. Both portable gauges and radiopharmaceuticals are typically transported in Type A packages. Meanwhile, the nuclear fuel cycle sector accounts for only 4% of total shipments. Type A packages are the most commonly used type of packages, with excepted packages being the second most commonly used. Type B packages account for only 4% of shipments, but carry 95% of the total activity shipped.

INTRODUCTION

In Canada, the Canadian Nuclear Safety Commission (CNSC) is the federal regulator responsible for regulating the use of nuclear energy and materials to protect health, safety, security and the environment, to implement Canada's international commitments on the peaceful use of nuclear energy, and to disseminate objective scientific, technical and regulatory information to the public. The CNSC's regulatory framework is based on the *Nuclear Safety and Control Act* (NSCA). Regulations specific to the transport of radioactive materials are set out in the *Packaging and Transport of Nuclear Substances Regulations, 2015* (PTNSR 2015).

This paper presents the findings of a study done by the CNSC to assess the number of RAM shipments made each year in Canada. It provides a short overview of previous Canadian and international surveys, includes the strategy and methodology followed for this study and, finally, provides an overview of the findings. This paper also offers suggestions for future studies.

SCOPE

In Canada, subject to the regulations, every organization that possesses, transfers, imports, exports, uses or abandons a nuclear substance must be licensed by the CNSC. There are approximately 1,500 licensees holding over 2,100 licences. All the licensees were contacted, including freight forwarders and carriers that ship and/or import-export radioactive materials.

The study involved collecting data on RAM shipments in Canada in 2021 and 2022. The study was broken down into the following six transport sectors: industrial, medical, nuclear fuel cycle, commercial, academic and research, and other. The transport sector is determined by the end use of the package contents. To improve the accuracy of the results, this study further broke down the sectors into ten strata (activity types): industrial (portable gauges), industrial (industrial radiography), industrial (fixed gauges), industrial (other), medical (nuclear medicine), medical (other), nuclear fuel cycle, commercial, academic and research, and other. If the end use of the package contents did not fit into one of the other five sectors, it was categorized as "other", such as activity type with no RAM shipments.

The survey requested data on:

- All types of CNSC regulated RAM transport packages, i.e., excepted packages, Type IP-1, Type IP-2, Type IP-3, Type A, Type B, Type H and fissile material packages
- Modes of transport used for shipment of these packages
- Number of each type of package shipped each year
- Activity (TBq) of the RAM contents shipped each year for these packages

PREVIOUS STUDIES

The following sections provide a brief overview of the previous studies conducted in Canada and by other countries on the number of shipments carrying RAM packages.

Previous Surveys Conducted in Canada

In 1948, the number of RAM shipments of medical products and instruments used in Canada totaled only 20. In the 1950s and 1960s, the number of RAM shipments started to increase substantially.

The first comprehensive survey was conducted in 1977, and it determined that approximately 440,000 RAM packages (including excepted packages) were transported in Canada [1].

In 1992, the Atomic Energy Control Board (AECB) conducted a survey and updated the data for RAM transport activity in Canada. The scope of the survey included material identification and activity, package and shipment types and numbers, transport index, mode of transport, transport distances, origin of shipment as well as import and export information. During the 1992 survey, about 350 licensees were sampled. The study concluded that about 1 million packages ($885,000 \pm 25\%$) (excluding excepted packages) are transported in Canada annually [2]. The results of the 1992 survey are still referenced in CNSC outreach presentations, stating that about 1 million shipments of RAM are made in Canada on an annual basis.

International Studies on the Transport of RAM

In 1981, the International Atomic Energy Agency (IAEA) initiated a program to gather global statistics from member states on transport activity [3]. A total of 49 countries responded. The data were extrapolated on the basis of gross domestic product and population. The report estimated that 18 million to 38 million RAM shipments were made annually in the early 1980s (1979-1982). The top 12 countries accounted for 99% of all package shipments. Canada was identified as the second largest shipper of radioactive materials, with some 613,000 packages (excluding excepted packages) shipped.

In 1999, the US Nuclear Regulatory Commission (NRC) conducted a study on the transport of RAM in the US to determine the number of RAM packages shipped and the number of shipments made in 1999 [4]. The study reported that in the US, the number of RAM shipments had increased to 18 million in 1999, compared with 2.8 million in 1985. It was also noted that 96.3% of the total number of RAM packages shipped were radiopharmaceutical shipments and 98% of those shipments were made by road.

In 2001-2002, a study was carried out on behalf of the European Commission by five expert organizations [5]. The data are generally provided for the late 1990s and early 2000s. Over 1 million packages of radioactive materials, primarily for use in medicine, research and industry, were transported each year in EU member states. Type A and excepted packages were the most frequently transported package types, and the highest number of shipments were by road. Fuel cycle shipments represented only a small fraction of the total radioactive material shipments, but were generally the largest contributor to the activity transported.

In 2002, the total number of packages transported in France was about 700,000, carried in about 410,000 shipments [5]. A new study published in 2013 shows that in France each year about 620,000 shipments are made by various modes of transport, carrying more than 900,000 packages [6]. The total annual number of radioactive material shipments in Germany is approximately 500,000, carrying about 700,000 individual packages [5, 7]. In the Netherlands, almost 300,000 packages are shipped annually, and more than 95% of these contain radiopharmaceuticals [5].

In the UK about 230,000 packages are shipped. As many as 86% of packages are shipped for the supply and distribution of medical radionuclides, and 8% are shipped by the nuclear industry. Meanwhile, 5% are gauges and industrial radiography sources, and 1% are consumer products. Most of the time, the packages are transported by road [5]. A new study conducted in 2009 reported that up to half a million packages containing radioactive materials are transported to, from and within the UK every year [8].

In other countries, consistent long-term data are generally available only for shipments of nuclear fuel. It was reported that globally, more than 15 million packages of radioactive material are transported each year on public roads, railways, and ships [9].

STRATEGY AND METHODOLOGY

The Survey

Approximately 1,500 CNSC licensees, which hold over 2,100 licences, were contacted to complete the survey. The survey requested data over a two-year period — 2021 and 2022. The numbers were averaged out for each year. Only the consignors were asked to respond (not the consignees), so that the same shipments would not be counted twice. A guidance note was included to help licensees respond to the questionnaire.

The questionnaire covered the following items:

1. Shipments made in the following six transport sectors: industrial, commercial, nuclear fuel cycle, medical, research and academic, and other.
2. Types of packages included: excepted, Type IP-1, Type IP-2, Type IP-3, Type A, Type B, Type C, Fissile (Type IP-F, AF, BF) and uranium hexafluoride (Type H).
3. Number of shipments for each type of package.
4. Number of packages shipped.
5. Total activity of each type of package (TBq) shipped annually.
6. Number of shipments made for each mode of transport (air, rail, road or sea).
7. Number of domestic, import, export and in-transit shipments.

Response Rate of the Survey

The response rate of the licensees and radiation safety officers (RSOs) contacted was 53%, which is within the targeted response rate.

Assumptions

The following assumptions were made in this study:

1. If multiple modes of transport were used for the same shipment, it was considered as a single shipment. However, it still counted toward the total number of shipments for each mode of transport. For example, if the same shipment was transported first by road, then by air, and finally by road again, it was counted as one shipment, but under the modes of transport, it was counted as one shipment by road and one shipment by air.
2. Portable gauges and exposure devices are frequently moved from one jobsite to another. If the same portable gauge or industrial radiography exposure device was transported multiple times over the course of a day, it was considered to be one shipment. However, if that same gauge or exposure device was transported the next day as well, this was considered as a new shipment.
3. Type IP-1 & Type H packages have been combined to protect the confidentiality of certain licensees.

Sources of Error

There are several possible sources of error in this survey that could skew the data. The largest source of uncertainty in the results is that certain types of licensees may be more likely to respond than others. For example, if a licensee that shipped larger quantities of radioactive material were more likely to respond since they interact with the CNSC more frequently, this would lead to an overestimation of the data. Using the stratified sampling method reduces issues in differences between licensees with different types of licences; however, it does not account for differences between licensees with the same licence types. For example, if a stratum consisted of 100 licensees and only the 20 largest licensees responded to the survey, the estimated number of packages shipped by the other 80 licensees would be much higher than the actual shipments by these licensees. Such skewing may have occurred in the data.

The Data Analysis

The data collected from the survey was primarily coded and analyzed using the Python and Excel VBA programming languages. Excel VBA was used to generate the personalized emails, collect information from emails and transfer them to either Excel or a text file database. Data analysis was completed in Python using stratified sampling. Stratified sampling effectively breaks down a large population into its constituent groups.

OVERVIEW OF SHIPMENTS THAT TOOK PLACE IN CANADA IN 2021 AND 2022

This section provides an overview of all RAM shipments in 2021 and 2022 in Canada.

Table 1 provides information on RAM shipments made annually by each mode of transport. At a 95% confidence limit, it is estimated that in Canada, the number of RAM shipments by all modes of transport ranges between 670,000 and 850,000, with an average of 760,000 shipments. The vast majority of these shipments are transported, at least in part, by road. Each of these shipments may contain any number of RAM packages.

Table 1: RAM shipments made annually by each mode of transport

Mode of Transport	2021-2022 Average	
	Number of Shipments	Range (95% Confidence)
Road	705,000	616,500 – 793,500
Air	50,000	39,900 – 60,000
Rail	1	N/A
Sea	495	405 – 585
Total	760,000	670,000 – 850,000

Table 2 provides information on the RAM shipments made annually by licensees in each stratum. The largest fraction of shipments were made by portable gauge licensees, accounting for almost 49% of total shipments. The second largest stratum is commercial licensees, accounting for almost 24% of total shipments and is responsible for the majority of radiopharmaceutical shipments to hospitals. Shipments associated with the nuclear fuel cycle account for only 4% of total shipments.

Table 2: RAM shipments made annually by each stratum

Stratum	2021-2022 Average		Fraction of RAM Shipments for Each Stratum
	Number of Shipments	Range (95% confidence)	
Portable gauge	370,000	286,000 – 454,000	49%
Industrial radiography	30,000	21,000 – 39,000	4%
Fixed gauge	4,400	2,300 – 10,000	0.6%
Nuclear medicine	130,000	113,000 – 146,000	17%
Medical (other)	1,700	1,000 – 2,500	0.2%
Industrial (other)	5,800	2,900 – 8,600	0.8%
Commercial	186,000	166,000 – 206,000	25%
Academic and research	4,200	2,900 – 5,400	1%
Nuclear fuel cycle	27,000	22,000 – 32,000	4%
Total	760,000	670,000 – 850,000	100%

Table 3 provides information on number of RAM shipments shipped annually by package type. Type A packages are the most commonly used type of package, accounting for 67% of the total RAM packages shipped. This is to be expected since Type A packages are used for the transport of portable gauges and radiopharmaceuticals and these account for the majority of shipments. The second most commonly used type of package is the excepted package. Type B packages account for only 4% of shipments, but carry 95% of the total activity shipped.

Table 3: Number of RAM packages shipped annually by package type

Package Type	2021-2022 Average		Fraction of RAM Packages Transported by Type of Package
	Number of Packages	Range (95% confidence)	
Excepted	150,000	132,000 – 168,000	17%
Type A	605,000	514,000 – 696,000	67%
Type AF	735	N/A	0.1%
Type B	34,000	23,500 – 44,500	4%
Type BF	470	N/A	0.1%
IP-1 & Type H	80,000	72,100 – 87,800	9%
IP-2	35,500	30,000 – 40,900	4%
IP-3	1,005	750 – 1,260	0.1%
Total	910,000	816,000 – 1,004,000	100%

Table 4 provides information on the RAM activity (TBq) carried by each type of package shipped annually. Type B packages account for 97% of the total activity carried by RAM packages.

Table 4: Average RAM activity by package type shipped annually

Package Type	2021-2022 Average		Fraction of RAM package activity by type of package
	Total Activity by Package (TBq)	Range (95% Confidence) (TBq)	
Excepted	17,500	11,700 – 23,300	1%
Type A	15,500	11,000 – 20,000	1%
Type AF	68	N/A	0.0%
Type B	1,660,000	1,360,000 – 1,970,000	97%
Type BF	45	N/A	0.0%
IP-1 & Type H	1,900	1,750 – 2,050	0.1%
IP-2	13,950	12,400 – 15,500	1%
IP-3	0.46	0.30 – 0.64	0.0%
Total	1,700,000	1,400,000 – 2,000,000	100%

SUGGESTIONS FOR FUTURE STUDIES

In a future study, the authors suggest that the number of shipments be related to accident data during the transport of RAM in order to calculate the probability of a transport accident involving RAM in Canada. An analysis of activity data along with event data would provide a foundation for assessing the radiological impact of transporting RAM. In addition to providing public information, this would also help with managing risk and allocating resources to regulate the industry.

With respect to incidents involving the transport of RAM, studies have been done and data are available. For example, there is currently an ongoing study by the CNSC titled “A Probabilistic Risk Assessment of Truck/Trailer Transportation of Radioactive Material in Canada” [10]. Accidents during radioactive material transport are very rare worldwide. Therefore, the objective of this study is to gather and analyze relevant Canadian road accident data for large trucks and develop a generic accident event tree specific to Canadian conditions. Future projects will be able to use this data to evaluate the probability of an accident considering the number of RAM shipments that take place every year.

CONCLUSION

This study collected information on the number of shipments that take place each year by different modes of transport, using different types of packages, for all transport sectors in Canada. The study estimates that in Canada, on average, there are approximately 760,000 RAM shipments each year involving 900,000 packages, with a total activity of about 1,700,000 TBq. The nuclear fuel cycle sector accounts for only 4% of the total shipments. The vast majority of these shipments are transported at least in part by road. Type A packages are the most commonly used type of package. Type B packages account for only 4% of shipments but carry 95% of the total activity shipped. The ability of a regulator to disseminate objective technical and regulatory information to the public on the RAM transport activity will help build public confidence in the quality of the regulator’s efforts for the safe transport of RAM.

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