Canada's Nuclear Regulator

Technical Assessment Report: **NAC-LWT Package Design for Transport of Highly Enriched Uranyl Nitrate Liquid**

December 2014

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

Technical Assessment Report: NAC-LWT Package Design for Transport of Highly Enriched Uranyl Nitrate Liquid

Également publié en français sous le titre : Rapport d'évaluation technique : Conception du colis NAC LWT pour le transport de solution liquide de nitrate d'uranyle hautement enrichi

Document availability

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Preamble

In April 2010, the governments of Canada and the United States (U.S.) committed to work cooperatively to repatriate spent highly-enriched uranium (HEU) fuel from Canada to the U.S. This cooperation is part of the Global Threat Reduction Initiative (GTRI), a broad international effort to consolidate HEU inventories in fewer locations around the world. This initiative promotes non-proliferation and global security by removing existing weapons grade material from Canada and transferring it to the U.S., which has the capability to reprocess it for peaceful purposes. It also eliminates a nuclear liability for future generations of Canadians.

In March 2012, Prime Minister Harper announced that Canada and the U.S. were expanding their efforts to return additional inventories of HEU materials, including those in liquid form. This includes highly enriched uranyl nitrate liquid (HEUNL) which is a by-product of medical isotope production. The HEUNL intended to be transported is currently stored at the Canadian Nuclear Laboratories (CNL) facility in Chalk River, Ontario.

To safely transport the HEUNL material, the American-based company NAC International Inc. (NAC) has submitted an application for the certification of a revised version of the currently certified NAC Legal Weight Truck (NAC-LWT) transport package for the intended transport of HEUNL. This package design must be independently certified by both the U.S. and Canada, starting with the U.S., as country of origin. Certification is required by the U.S. Nuclear Regulatory Commission (USNRC) and the U.S. Department of Transport (USDOT), and by the Canadian Nuclear Safety Commission (CNSC).

The scope of this technical assessment is for the purposes of the certification of the package design. The CNSC has not yet received an application to transport or export HEUNL to the U.S.

Canadian certification

In order to be certified in Canada, the NAC-LWT package must undergo stringent testing, which simulates both normal and hypothetical accident conditions of transport, including free-drop testing, puncture testing and thermal testing. The package must comply with the CNSC *Packaging and Transport of Nuclear Substances Regulations* (PTNSR). These regulations, based on the International Atomic Energy Agency (IAEA) *Regulations for the Safe Transport of Radioactive Material*, establish strict standards of safety which provide an internationally acceptable level of control of the radiation, nuclear criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material.

Once CNSC staff are satisfied that all regulatory requirements are met, a certificate is issued for the package design.

Should the NAC-LWT package be certified by the CNSC and the USNRC/USDOT, CNL, as the consignor, will be required to obtain a transport licence under the PTNSR, and an export licence under the *Nuclear Non-Proliferation Import and Export Control Regulations.* The information relating to the transport licence is prescribed information, and will not be disclosed publicly.

A summary of the overall regulatory framework for the transport of all radioactive materials (including the certification of transport packages) between Canada and the U.S. is shown in the figure below.

CANADA

Transport Canada (TC)

Responsibilities

- Approves Emergency Response Assistance Plan (ERAP)

Regulatory Requirements

- *Transportation of Dangerous Goods Act* (TDGA)
    - *Transportation of Dangerous Goods Regulations*

Canadian Nuclear Safety Commission (CNSC)

Responsibilities

- Issues package certificate
- Issues transport licence (includes routing, security plan and reference to TC-approved ERAP)
- Issues export licence
- Administers provisions of bilateral U.S./Canada nuclear cooperation agreement

Regulatory Requirements

- *Nuclear Safety and Control Act* (NSCA)
    - *General Nuclear Safety and Control Regulations*
    - *Packaging and Transport of Nuclear Substances Regulations*
    - *Radiation Protection Regulations*
    - *Nuclear Security Regulations*
    - *Nuclear Non-proliferation Import and Export Control Regulations*
- *Transportation of Dangerous Goods Act* (TDGA)
    - *Transportation of Dangerous Goods Regulations* for Class 7 (Radioactive Materials)

UNITED STATES

Department of Transportation (DOT)

Responsibilities

- Issues Competent Authority Certificate (CAC) validating NRC Certificate of Compliance (CoC) – issued after NRC CoC

Regulatory Requirements

- *Hazardous Materials Regulations* (HMR), Code of Federal Regulations Title 49 (49 CFR) (includes emergency response and security requirements)

Nuclear Regulatory Commission (NRC)

Responsibilities

- Issues package Certificate of Compliance (CoC)
- Approves transport routes based on DOT regulations

Regulatory Requirements

- *Title 10, Code of Federal Regulations* (10 CFR)
    - *Packaging and Transportation of Radioactive Material Regulations* (10 CFR Part 71)
    - *Standards for Protection Against Radiation* (10 CFR Part 20)
    - *Export and Import of Nuclear Equipment and Materials* (10 CFR Part 110)

Department of Energy / National Nuclear Security Administration (DOE/NNSA)

Responsibilities

- Manages the Global Threat Reduction Initiative (GTRI)
- Administers provisions of bilateral U.S./Canada nuclear cooperation agreement
- Approves transportation and security plans
- Authorizes shipments

Regulatory Requirements

- GTRI
- *National Environmental Policy Act* (NEPA)

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Executive Summary

This document presents the technical assessment performed by Canadian Nuclear Safety Commission (CNSC) staff of the application submitted by NAC International Inc. (NAC) for the certification of a radioactive material package design for the intended transport of highly enriched uranyl nitrate liquid (HEUNL). No prescribed information is included in this report.

The HEUNL intended to be transported is currently stored at the Canadian Nuclear Laboratories (CNL) facility in Chalk River, Ontario. It is intended to be transported as part of the broader international effort under the Global Threat Reduction Initiative (GTRI), led by the United States, to consolidate highly enriched uranium (HEU) inventories in fewer locations around the world. Removing existing HEU material from Canada and reprocessing it for peaceful purposes promotes non-proliferation and security.

In December 2012, NAC submitted an application, to both the United States Nuclear Regulatory Commission (USNRC) and the CNSC, for the certification of a revised version of the currently certified NAC-Legal Weight Truck (NAC-LWT) package design for the intended transport of HEUNL. Since the submission of the application in 2012, the USNRC and the CNSC have made several requests for additional information which have been addressed by NAC.

CNSC staff conducted a technical assessment of the application submitted by NAC for the certification of the NAC-LWT transport package to contain HEUNL, and are satisfied that it meets all Canadian and international regulatory requirements.

CNSC staff also conducted an environmental assessment (EA) under the *Nuclear Safety and Control Act* (NSCA). This assessment was taken into account in the review of the application for certification of the package. Staff concluded that the NAC-LWT package proposed by NAC for the intended transport of HEUNL will ensure the protection of the environment and health and safety of people.

The CNSC has not yet received an application to transport or export HEUNL to the U.S. Prior to the approval of any shipments of HEUNL in a certified package, the CNSC will ensure that all regulatory requirements are met. These requirements include the approval of a transport security plan by the CNSC for these shipments, that there is an Emergency Response Assistance Plan approved by Transport Canada in place, and that a CNSC export licence has been issued.

The CNSC is mandated to ensure that all nuclear activities are conducted in a manner that protects the environment, as well as the health, safety and security of workers and the public, while also implementing Canada's international obligations on the peaceful use of nuclear energy. The CNSC strongly values transparency and public consultation, and has provided up-to-date information on its website regarding the NAC-LWT package certification and the intended transport of HEUNL such as posting the original application from NAC on June 25, 2013. This technical assessment report, including the EA, is open for a public comment period of 30 days.

1.0 INTRODUCTION

1.1. Purpose and scope

The purpose of this document is to present the Canadian Nuclear Safety Commission (CNSC) staff assessment of the application submitted by NAC International Inc. (NAC) for the certification of a package design for the intended transport of highly enriched uranyl nitrate liquid (HEUNL). No prescribed information is included in this report.

This assessment is based on information submitted by NAC. The CNSC staff assessment focuses on whether the design of the package meets the regulatory requirements specified in the *Packaging and Transport of Nuclear Substances Regulations* (PTNSR) and the International Atomic Energy Agency (IAEA) *Regulations for the Safe Transport of Radioactive Material (2009 Edition)*, namely:

- package design requirements under normal conditions of transport
- package design requirements under accident conditions of transport
- criticality safety

1.2. Background

The HEUNL intended to be transported is currently stored at the Canadian Nuclear Laboratories (CNL) facility in Chalk River, Ontario. It is intended to be transported as part of the broader international effort under the Global Threat Reduction Initiative (GTRI), led by the Unites States (U.S.), to consolidate highly enriched uranium (HEU) inventories in fewer locations around the world. Removing existing HEU material from Canada and reprocessing it for peaceful purposes promotes non-proliferation and security.

For many years, HEU has been imported into Canada for use in the production of medical isotopes at the Chalk River laboratories, one of the world's largest producers of medical isotopes that are used in the diagnosis and treatment of cancer and other serious diseases. From 1986 until 2003, the target residue material from medical isotope production, a liquid containing HEU in the form of a highly enriched uranyl nitrate solution or HEUNL, was transferred to a double-walled stainless-steel vessel known as the fissile solution storage tank (FISST) located at the CNL facility in Chalk River. CNL is now planning to repatriate the HEUNL stored in the FISST back to the U.S.

In December 2012, NAC submitted an application to both the U.S. Nuclear Regulatory Commission (USNRC) and the CNSC for the certification of a revised version of the currently certified NAC-Legal Weight Truck (NAC-LWT) package design for the intended transport of HEUNL. Since the submission of the application in 2012, the USNRC and the CNSC have made several requests for additional information which have been addressed by NAC.

The USNRC is conducting an assessment of the application from NAC to ensure that all the applicable requirements under U.S. regulations are met. The CNSC is conducting an independent assessment from the U.S. of the NAC-LWT application against Canadian regulations, and will make a final decision on certifying the package in Canada if the package is certified in the U.S.

Since NAC is an American-based company, according to international regulations the package must first be certified in the U.S., the country of origin of the design.

In Canada, CNSC transport specialists, who must be accredited professional engineers, assess all applications concerning the certification of package designs. They draw on assistance from other CNSC experts as required to determine if all applicable regulatory requirements have been met.

The CNSC is mandated to ensure that all nuclear activities are conducted in a manner that protects the health, safety and security of workers and the public as well as the environment, while also implementing Canada's international obligations on the peaceful use of nuclear energy. The CNSC strongly values transparency and public consultation, and has provided up-to-date information on its website regarding the NAC-LWT package certification and the intended transport of HEUNL.

The CNSC has not yet received an application for a transport licence to ship HEUNL to the U.S. Should one be submitted, before authorizing the shipment in a certified NAC-LWT transport package, the CNSC will ensure that the applicant has in place:

- adequate provisions to ensure that radiation doses to the workers and the public will not exceed CNSC regulatory limits, and will be kept as low as reasonably achievable (ALARA) during the entire transport operation
- adequate provisions to protect the environment during the entire transport operation
- a transport security plan that has been submitted by the applicant and approved by the CNSC
- an emergency response assistance plan that has been submitted by the applicant and approved by Transport Canada
- a CNSC export licence in respect of the HEUNL

1.3. Highlights

CNSC staff assessed the application for certification of the NAC-LWT package design proposed for the intended transport of HEUNL from Canada to the U.S. for repatriation. The application from NAC, as well as supplemental information received from NAC in response to USNRC and CNSC requests for additional information, were reviewed and assessed by CNSC staff. Details of the CNSC staff assessment are presented in Section 2.0 of this report.

The assessment of the application was conducted using CNSC regulatory document RD/GD-364, *Joint Canada – United States Guide for Approval of Type B(U) and Fissile Material Transportation Packages*. This document describes the requirements to ensure compliance with the Canadian PTNSR, which incorporate, in part, the 1996 Edition (Revised) of the International Atomic Energy Agency (IAEA) *Regulations for the Safe Transport of Radioactive Material* (IAEA Regulations). In addition, the assessment of the application took into consideration the 2009 Edition of the IAEA *Regulations for the Safe Transport of Radioactive Material* (IAEA Regulations). The PTNSR and IAEA Regulations prescribe strict performance standards that must be met for the certification of transport packages that are designed to transport radioactive material. Key technical areas that were considered include structural, thermal, containment, shielding, criticality, operating procedures for the safe use of the package, inspection and maintenance, and quality assurance.

As part of their assessment of NAC's application, CNSC staff also conducted an environmental assessment (EA) under the *Nuclear Safety and Control Act* (NSCA). Staff considered the results of the EA in their review of the application for certification of the NAC-LWT package. A summary of the EA is presented in Section 3.0 and the complete EA information report is attached in Appendix A of this report.

1.4. Overall conclusions

CNSC staff conducted a technical assessment (Section 2.0 of this report) of the application submitted by NAC for the certification of the NAC-LWT transport package to contain HEUNL, and concluded that the package meets all Canadian and international regulatory requirements.

CNSC staff also conducted an EA under the NSCA. The EA was taken into account in the review of the application for certification of the transport package. In the EA information report (Appendix A of this report), staff concluded that the NAC-LWT package proposed by NAC for the intended transport of HEUNL will ensure the protection of the environment and health and safety of people.

2.0 CNSC TECHNICAL ASSESSMENT OF THE NAC-LWT PACKAGE DESIGN FOR THE INTENDED TRANSPORT OF HEUNL

2.1. General information

The NAC-Legal Weight Truck (NAC-LWT) package design is currently certified to transport highly enriched uranium (HEU) in solid form under Canadian transport certificate No. CDN/E173/-96 (Rev. 8) [1] and U.S. certificate No. USA/9225/B(U)F-96 (Rev. 53) [2]. The NAC-LWT has been safely used internationally for over 15 years for the safe transport of HEU and many other types of used nuclear fuel. NAC International Inc. (NAC) submitted on December 28, 2012 an application requesting the addition of highly enriched uranyl nitrate liquid (HEUNL) to the approved content for the NAC-LWT transport package design [3]. The same information submitted by NAC to the U.S. Nuclear Regulatory Commission (USNRC) was also submitted to the CNSC [4]. CNSC staff assessed this information independently from the USNRC to determine if Canadian regulatory requirements are met [5, 6]. The application from NAC as well as supplemental information received from NAC in response to CNSC and USNRC requests for further information [7, 8, 9], has been reviewed by CNSC staff. Non-proprietary versions of the key documents submitted to the CNSC by NAC, as part of their application, have been posted on the CNSC website (http://nuclearsafety.gc.ca/eng/reactors/research-reactors/nuclear-facilities/chalk-river/highly-enriched-uranium-in-canada.cfm).

NAC proposes to use the already certified NAC-LWT package with new specially designed inner containers for the intended transport of HEUNL. Each of these inner containers would be limited to a maximum of 58.1 L of HEUNL and four (4) of these inner containers would be placed within one NAC-LWT package for a maximum of approximately 232.4 L of HEUNL per NAC-LWT package.

CNSC staff conducted their assessment using CNSC regulatory document RD/GD-364, *Joint Canada – United States Guide for Approval of Type B(U) and Fissile Material Transportation Packages*. This document describes CNSC requirements for complying with the CNSC *Packaging and Transport of Nuclear Substances Regulations* (PTNSR), which incorporate in part the International Atomic Energy Agency (IAEA) *Regulations for the Safe Transport of Radioactive Material* (1996 Edition, Revised) as well as the 2009 Edition of the same IAEA Regulations, and are acceptable to the U.S. Department of Transportation (USDOT) and USNRC for complying with the U.S. regulations in Title 10, Part 71, *Packaging and Transportation of Radioactive Materials*, of the *Code of Federal Regulations* (10 CFR Part 71), which also incorporate in part the IAEA Regulations.

2.2. Transport package description and classification

The currently certified NAC-LWT package (used for the transport of HEU in solid form) is classified as a Type B package containing fissile material, in accordance with the PTNSR and IAEA Regulations.

The NAC-LWT package is a lead-shielded shipping package designed to transport various types of used nuclear fuel. This package is to be modified by adding inner containers to hold the HEUNL to the existing package. The package body consists of a 19 mm thick stainless steel cylindrical inner shell, a 146 mm thick cylindrical lead shield, a 30.5 mm thick cylindrical stainless steel outer shell and a cylindrical neutron shield tank. The inner and outer shells are welded to stainless steel top and bottom end forgings. An internal 76 mm lead disc and an 89 mm thick stainless steel plate provide additional bottom end shielding. The package lid is a 287 mm thick stainless steel stepped disc secured to the 362 mm thick top forging with twelve 25.4 mm diameter bolts. The neutron shield tank is 127 mm thick by 4,165 mm long and contains a 1 percent boron ethylene glycol/water solution.

The package is equipped on each end with aluminum honeycomb impact limiters that are installed at the time of transport and used to protect the package and the lid in the event of an accident. These impact limiters extend 305 mm over the ends of the package body. The top limiter is approximately 1,657 mm in diameter while the bottom one is approximately 1,530 mm in diameter. The overall length of the package, with impact limiters, is 5,890 mm. The maximum weight of the package with its content is 23,587 kg or 23.6 tons as specified in the certificate.

An illustration of the main package is shown in Figure 1, below. For shipment, the package will have impact limiters, which are part of the design of the package, installed at both ends of the main package, and be mounted inside an International Standards Organization (ISO) freight container, as shown in Figure 2.

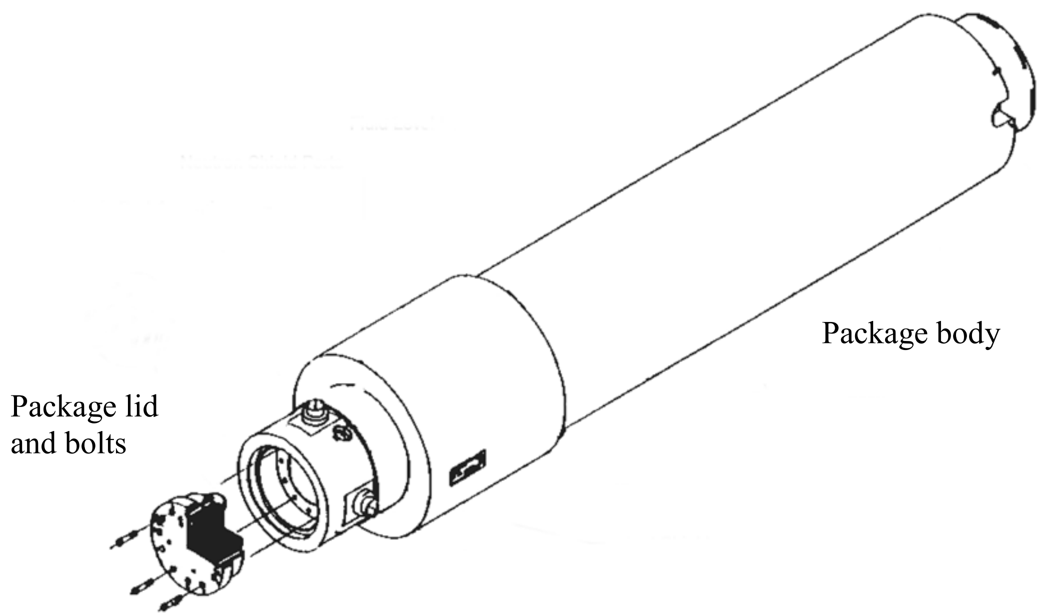

Figure 1: NAC-LWT main package

Figure 2: NAC-LWT with impact limiters

NAC proposes to modify the inner components of the previously certified NAC-LWT transport package by placing the HEUNL inside four inner containers that will be inserted into the package cavity. In their application submitted to the CNSC, NAC is requesting an amendment to the existing NAC-LWT package design certificate to authorize the placement of the four (4) inner containers containing the HEUNL inside the already certified outer package. These cylindrical inner containers have been specifically designed for the transport of the HEUNL and are to be constructed from Type 304L stainless steel. The design of the inner containers is proprietary and can therefore not be shown in this report. CNSC staff assessed various components of the inner containers, including the material to be used for their manufacture, and concluded that the material selected for the package is satisfactory for certification of the package and the safe transport of the proposed contents.

The weight of each empty inner container will be approximately 145 kg, while the total weight for an inner container filled with HEUNL is approximately 225 kg. Therefore, the maximum weight of the NAC-LWT package with the HEUNL contents as presented for transport is approximately 22,415 kg. This maximum weight is lower than the maximum weight of 23,587 kg authorized under the current certificate.

2.3. Characterization of the nuclear substances

As indicated above, NAC has requested a change to the authorized content for the NAC-LWT to include four inner containers designed to contain HEUNL. The HEUNL material packaged within these inner containers would be directly loaded into the NAC-LWT cavity.

HEU is uranium that has a concentration of U-235 greater than 20 weight percent. The HEUNL material consists of a solution of highly enriched uranyl nitrate, various other nitrates and water. HEU comprises less than 1percent of the total weight percent of the solution which is mostly water. The key physical, radiation protection and thermal characteristics of the HEUNL material are summarized in Table 1, below. Table 2 contains a summary of the main radionuclides in the solution (actinides, gamma emitters and their daughter products) used for the shielding calculations. To ensure conservatism, a bounding scenario was considered in the EA for releases to the environment wherein CNSC staff considered additional radionuclides, such as beta emitters.

Based on the composition of the HEUNL, CNSC staff confirmed that a Type B package is required for the safe transport of the material. CNSC staff evaluated and assessed the nuclear criticality associated with the HEUNL, which is addressed in Section 2.9 of this report.

Table 1: HEUNL characteristics

Parameter	Value
Maximum payload per inner container	58.1 L (15.35 gal) with a volumetric mass of 1.3 g/ml
Maximum package heat load (4 containers)	4.65 W
Maximum content (gamma emitters) [1]	333.0 GBq/L (9.0 Ci/L)
Maximum U-235 content [2]	7.4 gU/L

[1] Maximum content defined by source term and shielding evaluations.
[2] Maximum U content defined by criticality evaluation.

Table 2: Concentration of radionuclides in the solution (actinides, gamma emitters and their daughter products)

Isotope	Activity (Bq/L)
Nb-95	6.63E9
Nb-95m	25.35E9
Zr-95	25.35E9
Rh-103m	18.13E9
Ru-103	18.13E9
Rh-106	5.46E8
Ru-106	5.46E8
I-131	19.50E9
Xe-131m	19.50E9
Te-132	10.33E9

Isotope	Activity (Bq/L)
Ba-137m	70.19E9
Cs-137	70.19E9
Ba-140	58.50E9
La-140	58.50E9
Ce-141	42.88E9
Ce-144	8.19E9
Pr-144	8.19E9
Pr-144m	8.19E9
Nd-147	15.80E9
Eu-154	8.4E7

Isotope	Activity (Bq/L)
Eu-155	1.95E8
U-234	2.84E7
U-235	5.59E5
U-236	3.66E5
U-238	5.59E3
Np-237	4.51E3
Pu-239	1.3E6
Pu-240	8.99E4

2.4. Normal and accident conditions of transport

CNSC staff assessed the information provided by NAC in their application to confirm that the NAC-LWT package meets all regulatory requirements related to the normal and accident conditions of transport specified in the PTNSR and IAEA Regulations, as shown in Figure 3, since the content to be transported requires the use of a Type B package design for the transport of fissile material.

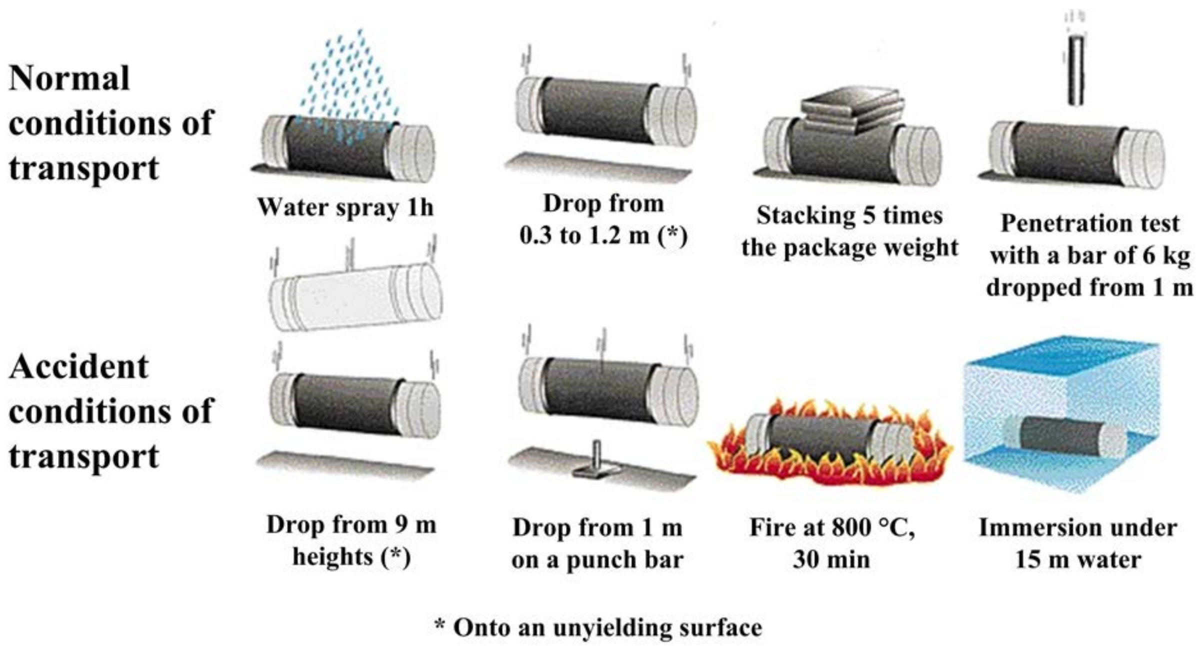

Figure 3: Type B regulatory requirements for normal and accident conditions of transport

As per the PTNSR and IAEA Regulations, the design of the package must take into account that accidents in transport do occur. As such, performance requirements are to be met through tests designed to simulate accident conditions. In order to ensure safety to the public and protection of the environment, the package must pass all of these stringent tests. If failures are detected during testing, a redesign is done in order to ensure that any consequence resulting from the test is mitigated through the package design. No package is certified if it fails to meet any of the testing requirements.

As presented in chapters 2 through 6 of the safety analysis report (SAR) submitted by NAC as part of their application, the required testing and/or analyses for the NAC-LWT under normal and accident conditions of transport for all contents and packaging configurations, including HEUNL, has been completed. The PTNSR and IAEA Regulations specify the criteria that have to be met in order to demonstrate that containment of the material is maintained during and after the tests, by limiting the maximum amount of leakage permitted, limiting the doses of radiation below regulatory limits and preventing a nuclear chain reaction to occur in transport.

CNSC staff performed a detailed review of the information presented for the HEUNL content under normal and accident conditions and confirmed that the package meets all regulatory requirements when transporting this liquid content.

2.5. Structural evaluation

CNSC staff assessed that NAC has properly analyzed the structural response of all the components of the inner containers and the NAC-LWT package to the normal and accident conditions of transport. NAC's analysis is presented in chapter 2 of their SAR, where the HEUNL configuration is reported to have a sufficient margin of safety under normal and accident conditions of transport.

2.5.1 Normal conditions of transport

The PTNSR and IAEA Regulations require that the package be subjected to the cumulative effects of the water spray test, 0.3 m free-drop test, stacking test and penetration test. The acceptance criterion for normal conditions of transport is that the package must maintain the required containment, shielding and subcriticality.

Water spray test - results

CNSC staff assessed the information submitted in support of this test requirement for the NAC-LWT package and confirmed that this test has no impact on the design of this package since water has no effect on the stainless steel materials used to fabricate the NAC-LWT package and the contents are protected in the sealed cavity.

Free-drop test - results

The free drop scenario for normal conditions of transport requires the NAC-LWT package to be structurally adequate for a 0.3 m drop onto a flat, unyielding, horizontal surface in the orientation that inflicts the maximum damage to the package.

In their application, NAC presented two drop orientations for the package used to demonstrate compliance with this regulatory requirement: lateral (side) and longitudinal (top end and bottom end) 0.3 m drops. The acceleration load is calculated as 25 g (equivalent to an impact of approximately 590 tons) for normal conditions of transport after a drop of 0.3 m. The "g" load is calculated from the displacement of the aluminium honey comb impact limiters using a maximum crush strength of 26.55 MPa or 3,851 pounds per square inches (psi) and the design package weight of 23,580 kg.

CNSC staff reviewed the analysis performed by NAC and confirmed that there is a significant safety margin in all cases of loadings under normal conditions of transport.

Stacking test - results

CNSC staff confirmed that stacking of the NAC-LWT package is prevented due to its shape and form, and that the safety of the package is maintained.

Penetration test - results

CNSC staff assessed the information in support of this test which requires that a bar of 3.2 cm in diameter and of a sufficient length to achieve a mass of 6 kg be dropped onto the weakest part of the package from a height of 1 m and confirmed that this test has no impact on the design of this package, since the results demonstrated that the 3.2 cm bar has no impact on the exterior shell of the package.

2.5.2 Accident conditions of transport

Under accident conditions of transport, the PTNSR and IAEA Regulations require that the package be subjected to the cumulative effects of a 9 m drop test, a puncture test, and finally a thermal stress test (described in Section 2.6 of this report). Although a water immersion test of 15 m is required for the HEUNL content, the NAC-LWT was subjected to a more conservative water immersion test at 200 m for one hour. The acceptance criterion for the accident conditions is that the package maintains the required containment, shielding and subcriticality following the completion of all tests.

Free-drop test - results

The free-drop scenario for accident conditions of transport is evaluated for lateral (side) and longitudinal (top end and bottom end) drops from a height of 9 m. The difference between the 9 m drop analysis and 0.3 m drop analysis is the magnitude of the impact force which is expressed in terms of a "g" factor. The impact load for a 9 m drop is calculated as 61g (equivalent to an impact of 1,440 tons) to assess the stresses in components of the containers in accident conditions. These "g" loads are conservatively based on a maximum crush strength of 26.55 MPa (3,850 psi) for the aluminum honeycomb impact limiters; although the design maximum crush strength is 25.34 MPa (3,675 psi). This impact force is similar to the impact test of a 22 ton spent fuel package installed on a flatbed truck that was impacted at 96.6 km/h (60 mph) into a 690 ton concrete block (https://www.youtube.com/watch?v=Bu1YFshFuI4&index=1&list=PLymk-3kcglbgIIiHl0yxoKnHOOLasRE3x) conducted in the late 1970's by Sandia National Laboratories for the USDOE. Following this test, the package was inspected and no damage was noted.

CNSC staff reviewed the analysis provided by NAC to assess the 9 m drop tests and found it acceptable, since there are adequate safety margins in all cases of loading. CNSC staff confirmed that the stresses resulting from the 9 m drop tests are well within the limits of the material used for the package in order to maintain containment, and prevent any leakage.

Puncture test - results

The puncture test requires the package to be dropped from a height of 1 m onto a puncture pin (a steel bar 15 cm in diameter and at least 20 cm long). The impact orientation of the package is required to be such that maximum damage is inflicted upon the package. The containment must be maintained after the test.

NAC analysed a total of four puncture tests on the NAC-LWT; (1) package side at midpoint, (2) centre of the package lid, (3) centre of the package bottom, and (4) package port covers. These tests cause maximum damage to the package. CNSC staff previously assessed this test requirement for the package containing other contents, such as highly enriched uranium in solid form and confirmed that this test has no impact on the design of this package and the package remains leak tight.

Water immersion test - results

NAC has demonstrated that the package will withstand an external pressure of 2 MPa (290 psi) for at least one hour. This pressure corresponds to a depth of water of 200 m. This evaluation bounds the 15 m water immersion required for all packages and the 0.9 m water immersion required for fissile material packages in accordance with the PTNSR and IAEA Regulations. CNSC staff previously assessed this test requirement for the package containing other contents and confirmed that this test has no impact on the design of this package. Since this test was performed on the external portion of the NAC-LWT package, which has not been modified for the HEUNL content, there will be no impact on the inner containers containing the HEUNL as a result of this test.

2.5.3 Liquid sloshing

CNSC staff assessed the information submitted by NAC as part of their application, to address the sloshing of the liquid within the inner container. NAC evaluated the potential effect of sloshing of the liquid content in a partially filled container. The fluid sloshing could affect the conditions of transport by either producing excessive accelerations or by amplifying the dynamic response for the drop cases. CNSC staff performed a review of the information provided by NAC and confirmed that the acceleration force from sloshing is equivalent to 1g which is significantly less than the drop load cases. Therefore, CNSC staff concluded that there would be no significant amplification of the dynamic forces and the package safety will be maintained.

2.6. Thermal evaluation

CNSC staff assessed the thermal analysis of the NAC-LWT package under normal and accident conditions, as presented in chapter 3 of the NAC SAR. The heat load of the HEUNL is far less than the heat load of the materials test reactor (MTR) fuel previously analyzed and approved for this package design. Therefore, CNSC staff confirmed that the maximum temperatures of the package components for the MTR fuel contents bound the maximum temperatures for the package components for HEUNL. CNSC staff therefore concluded that safety of the package will be maintained. The range of temperatures in the package under normal and accident conditions are discussed in the following sections.

2.6.1 Thermal stresses at low temperature

As per the PTNSR and IAEA Regulations, the effect of low temperature on the package and its content has to be evaluated. The minimum temperature to be used for the analysis is -40°C. At such temperature, the liquid content can freeze and due to the properties of the solution, expansion of the fluid in the frozen condition occurs.

The liquid solution will undergo a 2 percent volumetric expansion from ambient temperature to freezing temperature. However, since the inner container is partially filled (there is at least 3.8 L or 1 gallon of void space in each inner container), CNSC staff concluded that the expansion of the liquid solution will not have an impact on stresses in the inner container as there is an adequate margin of safety in free volume inside the inner container.

2.6.2 Normal conditions of transport

The temperatures of each of the components of the NAC-LWT package must be evaluated during normal transport conditions. The package must prevent components from exceeding their allowable performance temperatures when the liquid content is being transported. Components important to safety, such as seals, gamma and neutron shielding, must be maintained within their safe operating ranges. Also, the thermally induced stresses, in combination with pressure and mechanical load stresses must be maintained below allowable stress levels.

The PTNSR and IAEA Regulations require that the package be designed for an ambient temperature range from -40°C to +38°C for normal conditions of transport. The safety report submitted by NAC considers an ambient temperature range of -40°C to +55°C.

NAC performed thermal analysis of the package with the liquid solution using finite element code. The package is placed inside a standard International Standards Organization (ISO) freight container with solar insolation applied to the surface of the ISO freight container. A bounding heat load of 12.88 W is assumed for the liquid content which is located in the most inner part. The assessment of the heat load was based on a heat generation rate of 0.05 W/L. In order to ensure conservatism, the outer surface of the inner container was exposed to +56°C which corresponds to the maximum inner shell temperature of the package cavity.

The ASME code applicable to the material specification used in the manufacture of the inner containers specifies a maximum temperature of +426°C for stainless steel. The maximum temperature calculated for the inner container is +59.4°C which is significantly lower than the allowable temperature of +426°C for stainless steel under the ASME code. In addition, the PTNSR and IAEA Regulations require that the maximum temperature of any accessible external surfaces does not exceed +85°C. NAC evaluated the maximum surface temperature as +58°C. CNSC staff assessed the analysis provided by NAC and confirmed that the package complies with the temperature requirements specified in the PTNSR and IAEA Regulations.

2.6.3 Accident conditions of transport

The PTNSR and IAEA Regulations require that the package retain sufficient shielding and containment after the thermal test (exposure of the package to +800°C for 30 minutes).

The thermal test is preceded by the 9 m drop and puncture test described above. NAC has demonstrated that the only damage that occurs as a result of the drop and puncture tests that is of importance to the package thermal performance is damage to the neutron shielding. The effect of the loss of the neutron shielding would only slightly increase the dose rate at 1 m from the package from 0.02 mSv/h to 0.03 mSv/h. Further information on containment of the material is provided in Sections 2.7 and 2.8 of this report. Therefore, the thermal analysis assumes that the integrity of the neutron shield has been compromised to the extent that it is no longer present. For this test, NAC performed the thermal analysis of the package with the HEUNL using finite element analysis method. Under the thermal test conditions, the maximum temperature of the inner container shell is calculated as +97^{o}C while the exterior of the NAC-LWT package is exposed to 800^{o}C. The maximum +97^{o}C calculated for the shell of the inner container is below the allowable temperature for stainless steel (+426^{o}C).

CNSC staff assessed the analysis provided by NAC and confirmed that the package complies with the requirements specified in the PTNSR and IAEA Regulations following the accident conditions. The analysis demonstrated that the package will maintain sufficient shielding to limit the dose rate to less than 10 millisievert per hour (mSv/h) at 1 m for the package and remain leak tight.

From the results of the analysis performed, CNSC staff verified and confirmed that there would be no release of the inner content following the accident conditions of transport specified in the PTNSR and IAEA Regulations and that the dose rate at 1 m from the package would only slightly increase from 0.02 mSv/h to 0.03 mSv/h. Further information on containment of the material is provided in Sections 2.7 and 2.8 of this report.

2.6.4 Internal pressure

Since the content is liquid, the PTNSR and IAEA Regulations require that the effects of radiolysis and vapour pressure be taken into account in the analysis. In addition, the PTNSR and IAEA Regulations specify that the conditions to be taken into account assume that the content has been loaded for a period of one year and that minimum and maximum design temperatures are considered.

Therefore, the inner containers are designed not to release any contents during normal conditions of transport. The inner containers are loaded at atmospheric pressure and any pressurization of the package cavity will be caused by;

i) partial pressures associated with container backfill gas used to establish a free volume in the container,
ii) radiolysis gas generation by the contents, and
iii) vapour pressure.

The minimum design temperature of the package is -40^{o}C as specified by the PTNSR and IAEA Regulations. The maximum temperature within the package under normal conditions is +59.4^{o}C as calculated in Section 2.6.2 of this report.

Under these assumptions, NAC has determined that the pressure within the inner container would reach a maximum normal operating pressure (MNOP) of 0.50 MPa (72.3 psi) in a one year period, which is below the maximum limit of 0.7 MPa (101.5 psi) specified in the PTNSR and IAEA Regulations. CNSC staff verified the assumptions and confirmed that the safety of the inner containers will not be affected since it is shown in the analysis that they can sustain 0.79 MPa (114.5 psi) without leakage.

Table 3 provides a summary of pressures and temperatures reached by various components of the package as presented in the application.

Table 3: Summary of temperatures and pressures

Condition	HEUNL temperature	Pressure within the inner container	Temperature of the package cavity inner shell	Pressure within package cavity
Fill temperature	+20°C	N/A	N/A	N/A
Normal (cold)	-40°C	0.365 MPa (52.9 psi)	N/A	N/A
Normal (hot)	+59.4°C	0.500 MPa (72.3 psi)	+56°C	0.165 MPa (24 psi)
Accident (fire)	+97.2°C	1.087 MPa (157.7 psi)	+115.6°C	0.194 MPa (28.1 psi)

2.7. Containment evaluation

NAC has evaluated the containment for the NAC-LWT package in chapter 4 of their safety analysis report (SAR). No material is expected to be released from the inner containers based on the analysis performed for both normal and accident conditions of transport. Upon completion of fabrication, the package containment will be leak tested in accordance with the American National Standard (ANSI) N14.5-1997 standard, and must meet the requirements of the standard before being put into service.

The containment boundary for the NAC-LWT package consists of the NAC-LWT package cavity closed by the plug and seals. CNSC staff are satisfied that NAC has demonstrated in their application that the package will maintain a leak tightness of 1×10^{-7} ref-cm^3/sec as per ANSI N14.5-1997 during normal conditions of transport, as well as following the tests for accident conditions of transport. In addition, the applicant does not take credit for the inner containers in preventing a release inside the package cavity during accident conditions, thereby adding to the level of safety of the package design. CNSC staff reviewed the calculations provided and confirmed that NAC has adequately demonstrated leak tightness of the package under both normal and accident conditions of transport.

CNSC staff also performed an independent analysis of leakage from the package in the EA information report attached as Appendix A to this report. To be conservative, the maximum leakage rate specified in the PTNSR and IAEA Regulations was used, equivalent to a release of 0.033 percent of the HEUNL contents, and the effects on the environment assessed. Even under conservative assumptions, the EA information report concludes that the NAC-LWT package will ensure the protection of the environment and health and safety of people.

CNSC staff verified that containment of the material is maintained following an accident to prevent persons attending on the accident scene from receiving a significant amount of radiation from the content of the package.

2.8. Shielding evaluation

The PTNSR and IAEA Regulations limit the maximum dose rate to 2 mSv/h at the surface and 0.1 mSv/h at 1 m from the surface of a package. The regulations also require that the package retain sufficient shielding after the tests for accident conditions to ensure that the radiation level at 1 m from the surface of the package would not exceed 10 mSv/h.

CNSC staff assessed the shielding evaluation for the NAC-LWT package as presented in chapter 5 of the SAR. The dose rate on the exterior of the package was calculated with the package loaded with the maximum quantity of HEUNL. The NAC-LWT package, with the inner containers loaded with HEUNL, uses a concentric cylindrical arrangement of steel, lead, steel and water to provide gamma shielding and neutron shielding. The maximum dose rates under normal and accident conditions of transport are shown in Table 4.

The calculated dose rates show that even under accident conditions, with lead slumped (deterioration of gamma shielding) and the loss of neutron shielding, the regulatory limits are met and dose rates remain low at 0.03 mSv/h at 1 m from the package. CNSC staff assessed these calculations and confirmed that the liquid content is bounded by shielding calculations previously approved for other contents authorized for this package.

Table 4: Maximum calculated dose rates on the package

	Dose rate location	Maximum (mSv/h)	Limit (mSv/h)
Normal conditions of transport	Surface of package	0.06	2
	1 m from package surface	0.02 (TI of 2)	0.1 (TI of 10)
Accident conditions of transport	1 m from package surface	0.03	10

2.9. Criticality evaluation

For added enhancement of safety, packages containing fissile material such as HEUNL require additional analysis, since the material is able to sustain a nuclear chain reaction (i.e., go critical) under certain conditions. This phenomenon is well understood and can be analyzed in detail based on the physical characteristics of the material. The PTNSR and IAEA Regulations specify requirements for the assessment for criticality of an individual package in isolation for normal and accident conditions, as well as an array of packages under normal and accident conditions of transport.

CNSC staff verified that NAC has properly evaluated the criticality safety of the NAC-LWT package in chapter 6 of the SAR. The most reactive configuration of the content within the NAC-LWT package is evaluated. CNSC staff are satisfied that the most reactive HEUNL configuration under normal and accident conditions of transport evaluated does not raise any criticality concerns.

For the NAC-LWT package loaded with HEUNL, the criticality analysis was performed with the four inner containers, each carrying 64.3 litres of liquid solution containing up to 7.4 g/L U-235 for both normal and accident conditions. This adds a conservative margin against criticality since each inner container will be filled to a maximum of 58.1 L. The criticality model uses the MCNP5 v1.60 code with the cross section libraries validated for highly enriched uranyl nitrates. MCNP5 uses the Monte Carlo technique to calculate the k_{eff} of the system. The factor k_{eff} is the effective neutron multiplication factor, which is the average number of neutrons from one fission that cause new fission events. In order to prevent nuclear criticality, the factor k_{eff} must remain below 0.95 at any time to ensure that the NAC-LWT package containing the HEUNL remains subcritical (i.e. will not sustain a nuclear chain reaction) during normal and accident conditions of transport.

As a conservative assumption, the accident condition includes the loss of neutron shielding material and the impact limiters. The package array analysis is done by evaluating a package array with dry interior and exterior, for normal conditions of transport and optimum interior and exterior moderated array for accident conditions. No HEUNL transfer is assumed between containers.

The upper subcritical limit (USL) for maximum reactivity configuration, is calculated as 0.9366, which is below the maximum k_{eff} value of 0.95. A system is considered acceptably subcritical (i.e. will not sustain a nuclear chain reaction) if the calculated k_{eff} plus calculational uncertainties lies at or below the USL.

Table 5 below provides $k_{eff} + 2\sigma$ values, where 2σ (0.0018) is the calculational uncertainty, for both a single package and an array of packages during normal and accident conditions of transport. The maximum $k_{eff} + 2\sigma$ is calculated as 0.9137 for an array of packages in accident conditions, which is below the calculated USL of 0.9366, and below the k_{eff} factor of 0.95 to prevent nuclear criticality.

Table 5: Values of ($k_{eff} + 2\sigma$) under Normal and Accident Conditions of Transport

Geometry	Condition	$k_{eff} + 2\sigma$
Individual (single) package	Normal conditions	0.8996 + 0.0018
	Accident conditions	0.9017 + 0.0018
Array of packages	Normal conditions	0.9019 + 0.0018
	Accident conditions	0.9119 + 0.0018

NAC has demonstrated that the $k_{eff} + 2\sigma$ of an infinite array of the NAC-LWT package with the most reactive configuration of HEUNL is below the USL under normal and accident conditions. The transport criticality safety index (CSI), as defined in the PTNSR and IAEA Regulations, is therefore zero for the NAC-LWT package.

CNSC staff reviewed the criticality safety analysis of the NAC-LWT package for the transport of HEUNL and confirmed that the maximum value of k_{eff} is below the USL, which provides a sufficient safety margin of subcriticality and fully complies with existing national and international guides and practices.

CNSC staff also conducted independent simulations and derivation of the USL and evaluated supporting information presented in the NAC application in relation to criticality safety. The independent CNSC review confirmed that the applicant sufficiently demonstrated that the package containing HEUNL is safely subcritical in accordance with the PTNSR and IAEA Regulations.

2.10. Evaluation of operating procedures

In addition to the technical evaluation of the design, CNSC staff assessed the operating procedures submitted by NAC for the NAC-LWT package, with the inner containers loaded with HEUNL, to ensure that the package will perform safely as designed.

These operating procedures are described in chapter 7 of the SAR and include an outline of the information that focuses on the steps that are important in assuring that the package is performing safely; the loading, unloading and preparation for transport of the NAC-LWT package with the HEUNL, including the alternate port cover that is required for the shipment of the liquid content. The procedures also cover the loading and unloading of the inner containers and the pre-shipment leakage test and associated criteria that need to be met to ensure that the package is adequately prepared for shipment. Specific steps include radiation surveys, bolt torques, seal inspections, and the installation of tamper-proof seals.

CNSC staff verified that the fundamental steps needed to ensure that the package is properly prepared for transport are adequately described and are consistent with the package evaluation presented in the application. The operating procedures are consistent with maintaining occupational radiation exposures below CNSC regulatory limits and as low as reasonably achievable (ALARA), as required by CNSC Regulations. CNSC staff confirmed that the operating procedures adequately cover the important aspects related to the safety of the package while it is being prepared for intended transport.

2.11. Evaluation of acceptance tests and maintenance program

CNSC staff assessed the acceptance tests and maintenance program for the NAC-LWT package, with the inner containers loaded with HEUNL, as described in chapter 8 of the SAR, and ensured they meet regulatory requirements. These include tests to be performed on the package during manufacture, initial commissioning, as part of regular maintenance and prior to each use. Manufacturing tests are performed to confirm the shielding integrity, heat rejection capability, neutron absorption capacity and leak tightness of the package. Maintenance activities include visual inspection of components, seal replacement as necessary, periodic leak tests and bolt replacement as necessary.

Chapter 8 of the report also specifies the qualification tests required for the inner containers that will be used for the transport of the liquid content. These tests include hydrostatic pressure testing prior to first use after fabrication, and periodically during service (after every 50 fill/drain cycles) or after vent and/or drain valves are rebuilt or replaced, as well as structural weld testing by dye-penetrant examination.

CNSC staff reviewed the acceptance tests and maintenance program presented by NAC and are satisfied that it covers the important aspects related to the safety of the package while it is being fabricated, maintained and used.

2.12. Quality assurance evaluation

CNSC staff verified that the management system in place at NAC covers all aspects of quality assurance related to the package, from the design to the repair of packages, to ensure that the package fully complies with the approved design.

NAC has a USNRC-approved quality assurance program. The addition of the HEUNL contents has not changed the quality assurance evaluation for the package presented by NAC.

CNSC staff are satisfied that the management system in place at NAC for the design, manufacture, testing, documentation, use, maintenance and inspection of the package continues to be in accordance with Certificate No. USA/9225/B(U)F-96, and the PTNSR and IAEA Regulations.

3.0 ENVIRONMENTAL ASSESSMENT

CNSC staff conducted an environmental assessment (EA) under the *Nuclear Safety and Control Act* (NSCA) of the information submitted by NAC, including the supplemental analysis completed by the U.S. Department of Energy [10]. The EA was taken into account in the review of the application for certification of the NAC-LWT package to ensure the protection of the environment and the health and safety of people.

CNSC staff prepared an EA information report, attached as appendix A, which focuses on the following areas:

- dose to the public and workers during normal transport conditions
- dose to the public and workers during severe transport accident conditions, including impacts on drinking water.
- emergency response planning to mitigate potential environmental effects during a transportation accident

Staff concluded in the EA information report that the NAC-LWT package proposed by NAC for the intended transport of HEUNL will ensure the protection of the environment and the health and safety of people.

4.0 CONCLUSIONS

CNSC staff completed a technical assessment of the application submitted by NAC for the certification of the proposed NAC-LWT transport package to contain HEUNL, and are satisfied that it meets all Canadian and international regulatory requirements for certification. This NAC-LWT package is intended for the transport of HEUNL stored at the Canadian Nuclear Laboratories (CNL) in Chalk River, Ontario, to the U.S. for repatriation.

The proposed NAC-LWT package design to contain HEUNL is a modified version of the NAC-LWT package that is currently certified for the transport of various solid contents. The application from NAC, as well supplemental information received from NAC in response to USNRC and CNSC requests for additional information, have been reviewed and assessed by CNSC staff.

CNSC staff also conducted an environmental assessment (EA) under the *Nuclear Safety and Control Act*. In the EA information report (appendix A), staff conclude that the NAC-LWT package proposed by NAC for the intended transportation of HEUNL will ensure the protection of the environment and the health and safety of people.

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LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
EA	Environmental Assessment
ERAP	Emergency Response Assistance Plan
FISST	Fissile Solution Storage Tank
GTRI	Global Threat Reduction Initiative
HEU	Highly Enriched Uranium
HEUNL	Highly Enriched Uranyl Nitrate Liquid
IAEA	International Atomic Energy Agency
NAC	NAC International Inc.
NSCA	*Nuclear Safety and Control Act*
PTNSR	*Packaging and Transport of Nuclear Substances Regulations*
SAR	Safety Analysis Report
TI	Transport Index
U.S.	United States
USDOE	United States Department of Energy
USDOT	United States Department of Transport
USL	Upper Sub-critical Limit
USNRC	United States Nuclear Regulatory Commission

APPENDIX A: ENVIRONMENTAL ASSESSMENT INFORMATION REPORT: TRANSPORTATION OF HIGHLY ENRICHED URANYL NITRATE LIQUID

Canada's Nuclear Regulator

Environmental Assessment Information Report: **Transport of Highly Enriched Uranyl Nitrate Liquid**

December 2014

Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canada

Environmental Assessment Information Report: Transportation of Highly Enriched Uranyl Nitrate Liquid

Également publié en français sous le titre : Rapport d'information sur l'évaluation environnementale : Transport de nitrate d'uranyle liquide hautement enrichi

Document availability

This document can be viewed on the CNSC website at nuclearsafety.gc.ca. To request a copy of the document in English or French, please contact:

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1. Introduction

At a public meeting of the Commission held on May 16, 2013, Canadian Nuclear Safety Commission (CNSC) staff made a commitment to conduct an environmental assessment (EA) under the *Nuclear Safety and Control Act* (NSCA) concerning the transport of highly enriched uranyl nitrate liquid (HEUNL). The EA supports the CNSC's regulatory process by ensuring adequate provisions are in place for the protection of the environment and the health and safety of Canadians before an activity is carried out.

The purpose of this report is to document the results of the EA that was conducted for NAC International Inc's (NAC's) application for the certification of a package to transport HEUNL. No decision will be rendered on the EA information report itself; however, the information will be considered by the CNSC when making a regulatory decision.

This report is based on information submitted by NAC, and work completed by CNSC staff, and focuses on the following areas:

- dose to the public and workers during normal transport conditions (section 2.2)
- dose to the public and workers during severe transport accident conditions, including impacts on drinking water (section 2.3)
- emergency response planning to mitigate potential environmental effects during a transportation accident (section 3.0)

1.1 Background

In 2012, the United States (U.S.) and Canada signed an agreement for the repatriation of HEUNL stored at the Canadian Nuclear Laboratories' (CNL) Chalk River Laboratory (CRL) site. To support this repatriation agreement, NAC, under contract with CNL, has submitted an application to the CNSC for the approval of a certified Type B package to transport HEUNL currently stored at CRL.

The proposed package, identified as the NAC-Legal Weight Truck (NAC-LWT) package, is the same Type B transport package that has already been approved by the CNSC [1] and U.S. Department of Transport (USDOT) [2], and used to transport highly enriched uranium (HEU) in solid form. CNL uses this package to safely transport HEU in solid form from CRL to the U.S. as part of a broad international effort to consolidate HEU inventories in fewer locations around the world. Such efforts promote non-proliferation and security by removing existing HEU material from Canada and reprocessing it for peaceful purposes (e.g., nuclear power production).

NAC is now proposing to use the NAC-LWT with a specially designed inner cavity which consists of four containers each carrying 58.1 litres (L) of HEUNL [3]. The NAC-LWT would be then be loaded into an International Standards Organization certified container, and one container would be loaded onto each truck. As the design and contents of the package are changing, certification is required by the CNSC, the U.S. Nuclear Regulatory Commission (USNRC) and the USDOT.

NAC has developed 10 major USNRC-licensed cask systems and has licensed its cask technology through competent authority validations in more than 35 countries, including Canada. Using the licensed casks, NAC has safely completed more than 3,700 cask movements of spent fuel, high-level waste and other nuclear materials.

Canada has an excellent safety record for the transport of nuclear substances, with more than a million packages containing radioactive material being safely transported (i.e., no loss of containment) in Canada each year, in various chemical and physical forms, including liquid. In accordance with the CNSC's legislative mandate and regulatory framework under the NSCA, the CNSC will not allow the shipment of any nuclear materials unless it is convinced that the health, safety and security of Canadians and the environment are protected.

Should the NAC-LWT be certified by the CNSC and the USNRC/USDOT, CNL will be required to obtain a transport licence and an export licence under the NSCA and its regulations.

1.2 Regulatory requirements

The CNSC will ensure that the packaging and transport of the HEUNL will meet all applicable regulatory requirements for the protection of human health, and the environment, before making a regulatory decision.

Packaging

The package must comply with the *Packaging and Transport of Nuclear Substances Regulations* made under the NSCA, and with the equivalent U.S. regulations; both are based on the International Atomic Energy Agency (IAEA) *TS-R-1, Regulations for the Safe Transport of Radioactive Material* (IAEA Regulations*)*, and must be approved by the USNRC/USDOT and the CNSC. The IAEA Regulations establish standards of safety, which provide an acceptable level of control of the radiation, criticality and thermal hazards to persons, property and the environment that are associated with the transport of radioactive material.

As per the IAEA Regulations, the package must be demonstrated to meet the performance tests specified in the regulations to simulate both normal and accident transport conditions. These tests include the cumulative effects of a free-drop test from a height of 9 meters (m), a puncture test, and a 30-minute thermal test at 800°C. Since the package will contain fissile material, additional conditions are imposed in the regulations to ensure that the package remains subcritical during normal and accident conditions of transport.

Transport

In order to transport the HEUNL, CNL is required to obtain a CNSC transport licence under the *Packaging and Transport of Nuclear Substances Regulations*, in addition to a CNSC export licence under the *Nuclear Non-proliferation Import and Export Control Regulations*. Under Transport Canada's *Transportation of Dangerous Goods Regulations*, CNL requires an approval of the emergency response assistance plan (ERAP) by Transport Canada.

In addition to the ERAP, CNL is required to submit a written transportation security plan in accordance with CNSC regulatory guide G-208, *Transportation Security Plans for Category I, II and III Nuclear Material*.

Stringent security plans for each shipment avoid any risk of the material falling into the hands of unauthorized persons or organizations. For the protection of the public, information on specific shipment details is considered prescribed, which means the information is limited to individuals and authorities who have a legitimate need to know, such as police and fire departments. The transportation routes and security measures put in place are pre-approved and agreed to by authorities in both Canada and the U.S.

Transport Canada regulations also require the consignor (CNL) to display a 24-hour emergency telephone number on all shipping documents that accompany each shipment. This ensures appropriate technical assistance is immediately available to emergency first responders.

2. Dose Assessment

The U.S. Department of Energy (USDOE) completed EAs in 1996 [4] and 2000 [5] investigating the impacts of transferring HEU in solid form from Canada to the U.S. In 2013, the USDOE conducted a supplemental analysis [6] that assessed the risks associated with the transport of HEUNL to support the previous EAs. The USDOE supplemental analysis concluded that the impacts to the environment, workers and the public are acceptable and would not be significantly different from the previous EA [4].

This EA information report focuses on the dose assessment that was conducted by the USDOE in its supplemental analysis, and two independent assessments carried out by CNSC staff [8, 9]. Although the packages are designed to carry four containers each with 58.1 L of HEUNL, CNSC staff assumed a maximum volume of 64.3 L for added conservatism. Since the shipment routes are not publicly disclosed and are classified as secret, representative (conservative) exposure scenarios relative to a given shipment were assumed in all cases.

2.1 CNSC regulatory dose limits

The CNSC's *Radiation Protection Regulations* set dose limits on the amount of radiation the public and nuclear energy workers can receive from activities licensed under the NSCA. These regulations require every licensee to implement a radiation protection program that keeps the amount of exposure to ionizing radiation "as low as reasonably achievable" (ALARA). Radiation dose limits are set in accordance with recommendations of the International Commission on Radiological Protection, as well as IAEA standards and guides.

In Canada, the CNSC sets the dose limits for workers and the public. The effective dose limit for members of the public is 1 millisievert (mSv)/year. The effective dose for nuclear energy workers is 50 mSv/year and 100 mSv/5 years. During the control of an emergency and the consequent immediate and urgent remedial work, the annual effective dose to a person shall not exceed 500 mSv. Should an emergency occur, the CNSC ensures adequate measures are in place to minimize worker and public exposure.

Canadians are exposed to many sources of natural and artificial (man-made) radiation in their everyday lives. Natural radiation accounts for approximately 60 percent of an average Canadian's annual dose, while artificial radiation (mostly from medical procedures) accounts for the other 40 percent of the annual radiation exposure. There is no difference between the effects caused by either natural or artificial radiation. Table 1 provides a comparison of natural and artificial sources of radiation to the regulatory dose limits set by the CNSC.

Table 1: A comparison of CNSC regulatory dose limits to natural and man-made sources of radiation

Dose (mSv)	Limit or type of exposure
30–100	Radiation dose from a full body computed axial tomography (CAT) scan
100	Five-year radiation dose limit for nuclear energy workers
50	Annual radiation dose limit for nuclear energy workers
1.3–4.1	Range of annual Canadian background dose (e.g., cosmic, terrestrial, inhalation, ingestion)
1	Annual public radiation dose limit
0.1–0.12	Dose from lung X-ray
0.01	Dose from dental X-ray
0.01	Average dose due to air travel
0.0000098	A resident living 30 m from the highway used to ship the containers

More information on radiation and radiation doses can be found on the CNSC website at: nuclearsafety.gc.ca/eng/resources/radiation/index.cfm

2.2 Normal transport conditions

Dose to the public

The risks from normal transport conditions are limited to external exposure to gamma and neutron radiation from the radionuclides sealed within the cask, as identified in the safety analysis report (SAR) [7] submitted by NAC. The USDOE identified the three receptors presented in table 2 to represent the general public for the purposes of its assessment. These receptors were selected, as they were considered to be representative of individuals most likely to be exposed. The doses received by these receptors per shipment are provided in table 2.

Table 2: USDOE's estimates of dose per shipment for three representative receptors

Receptor	Dose (mSv)/shipment
A person in traffic for 30 minutes located 1.2 m from the surface of the shipping container	0.15
A resident living 30 m from the highway used to ship the container	0.0000098
A service station worker standing 16 m from the shipping container for 50 minutes	0.0083

CNSC staff agree that these three receptors likely represent individuals who may be exposed to the highest doses. To verify the doses calculated by the USDOE, CNSC staff completed an assessment [8] using two methods. The first method considered the input parameters used by the USDOE, but also included the estimated radionuclide inventory from the SAR [7] and CNL. The second method assumed a dose rate of 0.1 mSv/hr at 1 m, regardless of the inventory, based on the Transport Index (TI). The TI is the maximum radiation level allowed at 1 m from the package based on IAEA Regulations. The TI method is more conservative than the inventory method, as the allowable dose rate would not likely be observed based on the robust package design. A package must meet the appropriate TI in order to be certified. The results of the CNSC assessment are provided in table 3.

Table 3: CNSC dose per shipment for three representative receptors

Receptor	Inventory based dose (mSv/shipment)	TI-based dose (mSv/shipment)
A person in traffic for 30 minutes located 1.2 m from the surface of the shipping container	0.0044	0.035
A resident living 30 m from the highway used to ship the container.	0.0000013	0.0000034
A service station worker 16 m from the shipping container for 50 minutes.	0.00108	0.0026

It is extremely difficult to estimate the number of events that each receptor may be exposed to; however, CNSC staff believe it is reasonable to assume that the probability that an individual would be exposed to multiple shipments is very low, with the exception of the resident living near the roadway. Assuming that this resident is exposed to a maximum of 60 shipments, the total estimated dose would be 0.0006 mSv from the USDOE assessment and 0.0002 from the CNSC's assessment.

Conclusion

CNSC staff conclude that the USDOE analysis is sufficiently conservative and thorough to demonstrate protection of the public, as the dose rates per event are well below the regulatory dose limit of 1 mSv/year.

Dose to worker

CNSC staff also assessed the dose to the driver by using the same dose assessment methods described in the previous section. The dose to the driver is provided in table 4. The number of shipments that any single driver would be involved in is unknown; however, as carriers of class 7 dangerous goods, these workers are subject to the radiation protection programs of their employers, and the dose control and monitoring methods specified therein. Radiation protection programs are designed to limit worker exposure and ensure the radiation dose for nuclear energy workers (e.g., the driver) remain below regulatory limits of 50 mSv/year and 100 mSv/5 years.

Table 4: CNSC assessment of the dose to the driver per shipment

Receptor	Inventory based dose (mSv/shipment)	TI-based dose (mSv/shipment)
Driver located 2 m from the surface of the shipping container for a maximum of 26 hrs (1700 km at 65 km/hr)	0.12	0.94

In the U.S., commercial drivers are subject to Occupational Safety and Health Administration regulations, which limit the whole body dose to 50 mSv/year, and the USDOT limit of 0.020 mSv/hour in the truck. The USDOE concluded that the regulatory regime would ensure that the dose to the driver will remain within the regulatory limit.

Conclusion

CNSC staff conclude that the dose to the driver remains low and well below the annual dose limit for nuclear energy workers.

2.3 Accident transport conditions

Land based accidents

The proposed Type B package is designed to withstand accident conditions of transport with no release of material from the package. However, both the USDOE and CNSC staff completed assessments concerning potential dose from an extremely low probability (a probability of occurrence of 6.6 x 10^{-12} per year) transportation accident involving the potential release and dispersal of radioactive material into the environment. Although

CNSC staff consider this accident scenario to be non-credible, the dose assessment was completed based on previous experience that demonstrated this could be a potential area of interest.

The USDOE performed an assessment of potential doses to populations and the most exposed individual from the most severe transportation accident involving a release. The accident is assumed to be a severe impact in conjunction with a long-duration fire. The maximum probability of this occurring was estimated by the USDOE to be 6.6×10^{-12} per year. The USDOE dose result to the most exposed individual was 2.1 mSv.

CNSC staff's approach was to assess the dose to the most exposed individual as a result of a severe accident. In accordance with IAEA Regulations, the package is designed to release only a fraction (0.033 percent) of the inventory, following a severe accident. The CNSC identified the two receptors presented in table 5 that could reasonably represent highly exposed individuals for the purposes of the assessment. The 30-minute time scale for two scenarios was deemed conservative, as first responders would likely move people away and cordon off the area within this timeframe.

Table 5: CNSC assessment of the accident conditions for three representative receptors

Receptor	Dose (mSv)/event
A person standing in the centre of a 1 m radius spill of 0.033% of the inventory of the Type B package for 30 minutes	0.819
A person standing in the centre of a 10 m radius spill of 0.033% of the inventory of the Type B package for 30 minutes	0.009

Conclusion

Based on both the USDOE's and CNSC staff's analysis of land based accident scenarios, CNSC staff conclude that even under extremely unlikely accident conditions, the doses to the most exposed individuals remain low and well below the emergency regulatory dose limit for nuclear energy workers and the public.

Aquatic based accidents

CNSC staff completed an assessment [9] that looked at the potential impacts on major water bodies during an accidental release on a bridge near the outlet of Lake Ontario and near the Ottawa River. These two major systems are the most likely ones to be affected on a direct transport route. The probability of this type of accident is extremely low – lower than the land based accident of 6.6×10^{-12} – as the distances travelled on bridges near these water bodies are only a fraction of the total distance travelled, thereby reducing the overall probability of an accident.

In Canada, the drinking water quality criteria are based on a limiting dose of 0.1 mSv/year during normal conditions, and 1 mSv/year during an emergency, as set by Health Canada [10, 11]. The 1 mSv/year radiation protection basis for protecting drinking water during emergencies is the same as the public dose limit in the *Radiation Protection Regulations* made under the NSCA. In comparison, the IAEA emergency criteria are based on a limiting dose of 10 mSv/year.

The major factor in determining potential environmental impacts is the dilution potential of the receiving water body. CNSC staff have a good understanding of the dilution potential of Lake Ontario and the Ottawa River based on monitoring of historic spills, dye tracer experiments conducted by CNL and aquatic dispersion modeling.

Similar to the land-based accident scenarios, and commensurate with IAEA Regulations, CNSC staff assumed a 0.033 percent release of inventory from the package into the receiving water bodies. The assessment concluded that in Lake Ontario, concentrations of radionuclides after a spill would be well below human health and environmental protection guidelines. This is primarily attributed to the large volume of water and high flow rates observed in Lake Ontario.

For a spill into the Ottawa River, the assessment concluded that normal drinking water quality criteria set by Health Canada would be met within 0.5 kilometres of the location of the spill (assuming the consumption of drinking water for one year), as shown in table 6. Given the low expected doses, the nature of any potential release and timely remediation efforts, no effects on human health would be expected. Furthermore, given the duration of the route and small number of bridge crossings, it is highly unlikely that an accident would occur within 0.5 kilometres of a drinking water supply plant.

Table 6: CNSC assessment of dose to an individual from the drinking water pathway following an accidental spill into the Ottawa River

Distance from spill (km)	Dose (mSv)
0.5	0.084
1	0.0454
5	0.0109
10	0.0059

In the unlikely event that an accident were to trigger intervention by government authorities at a drinking water supply plant, this would involve continuous monitoring, and possible temporary withdrawal of drinking water from public consumption until the levels of radioactivity diminished to acceptable levels.

Conclusion

CNSC staff conclude that the potential environmental impacts of severe transportation accidents resulting in a release to Lake Ontario or the Ottawa River would be minimal. Confidence on this conclusion is largely due to the multiple levels of conservatism included in the assessment, the short-term nature of any impacts, and the extremely low probability of any accident occurring over or near a major water body.

3. Emergency Response and Preparedness

3.1 CNSC oversight

The CNSC has a dual role in nuclear emergency management. First, in accordance with the mandate established by the NSCA, the CNSC maintains regulatory oversight of nuclear emergency activities, plans and procedures of the licensee. Second, as a federal agency, the CNSC participates in Canada's whole-of-government response to a nuclear emergency in accordance with the requirements of both the Federal Emergency Response Plan (FERP) and the Federal Nuclear Emergency Plan (FNEP).

The CNSC has developed a *Strategic Emergency Management Plan* (SEMP) [12] that details how the CNSC conducts emergency management at the strategic level in accordance with its mandate. The SEMP also links CNSC emergency management with the roles and responsibilities assigned to the CNSC in the FERP and the FNEP. The FERP is the government of Canada's "all-hazards" response plan, while the FNEP is an annex to the FERP, providing the supplemental and specific multi-departmental and inter-jurisdictional arrangements necessary to address the health risks associated with a nuclear emergency.

The CNSC has also developed a *Nuclear Emergency Response Plan – Master Plan* (NERP Master Plan) [13] that describes the CNSC's tactical response to emergencies that fall within its mandate, including transportation accidents. Additional NERP supporting plans provide additional details for response to a specific emergency. The Transportation Support Plan is currently under development.

For off-site transportation emergencies, the provincial, territorial or municipal government is the appropriate responsible authority for offsite actions. Provincial and territorial governments have the primary responsibility for protecting public health and safety, property, and the environment within their border. They are also the primary authorities for informing the public about protection actions and offsite conditions. CNL emergency response plans and procedures discussed in section 3.3 outline the actions to be taken by CNL to support the appropriate responsible authority for offsite actions.

CNSC staff will ensure emergency response planning is harmonized with the appropriate authorities through the SEMP and NERP. The CNSC ensures that it has the capacity to respond and capability to assist whenever requested by a responsible authority or first responder.

3.2 CNSC response

All transportation emergencies require prompt actions by first responders and expert authorities (e.g., CNSC, CNL) to assess the presence and/or extent of the consequences, confine the hazard and prevent the spread of contamination. In all cases, response time is critical, whether it refers to alerting CNSC representatives or the establishment of a prompt technical link between local first responders and the appropriate response staff at CNSC headquarters.

The CNSC will provide the necessary regulatory control, advice and guidance, and resources required to ensure public and environmental protection from the radiological effects of the event.

Upon notification of a transportation emergency, the CNSC Nuclear Emergency Organization determines whether the Emergency Operations Center (EOC) at CNSC headquarters should be activated. The EOC is the control centre for the CNSC's tactical response to an emergency. It is the location where the CNSC emergency response objectives are determined, and information is collected, displayed, shared with the public and other jurisdictions, and stored. The EOC can be activated 24 hours a day, seven days a week, and is staffed during an emergency with appropriate technical experts and support staff.

Once the EOC is activated, the CNSC's response is based on the following six response objectives:

- manage the CNSC EOC response
- assess the safety significance of the emergency
- enforce relevant regulatory and licence conditions
- provide technical advice and support
- coordinate and cooperate with external organizations
- communicate on the CNSC's response

Following an emergency, the EOC would be demobilized; and the CNSC may need to attend special standing committees in Parliament to provide information on the emergency event.

3.3 CNL emergency response plans and procedures

To minimize the potential dose received by workers and the public during an accident event, the *Packaging and Transport of Nuclear Substances Regulations* requires CNL to have an emergency response assistance plan (ERAP) approved by Transport Canada under section 7 of the *Transportation of Dangerous Goods Regulations*.

CNL has designed the *Emergency Response Plan for Off-site Transportation Accidents Involving Radioactive Material* [14], which constitutes an ERAP, to meet Transport Canada's regulatory requirement. Transport Canada has approved CNL's plan for the purposes of meeting the regulations for currently approved transportation activities. The plan was developed to ensure CNL acts in a manner consistent with the intent to protect public safety, property and the environment in the event of an accident involving the transportation of radioactive material.

A mutual aid assistance agreement exists between CNL, Ontario Power Generation, Hydro Quebec, the New Brunswick Electric Power Commission and Bruce Power. Under the agreement, the nuclear facility closest to the transportation incident will provide the initial response regardless of the origin, destination and ownership of the shipment until the response team from the owner of the material arrives on the scene.

The main steps in CNL's emergency response plan [14] and procedures [15] are outlined below.

CNL response to a transportation accident is initiated through the CRL Central Monitoring Room (CMR), which is staffed 24 hours a day, seven days a week. Accident notification may come from the driver, emergency personnel (e.g., police, fire fighters), Canadian Transport Emergency Centre (CANUTEC), another agency or a private citizen. CANUTEC is operated by Transport Canada and provides a national advisory service staffed by professional scientists experienced and trained in interpreting technical information and providing emergency response advice.

Local first responders are to follow instructions from the Transport Canada Emergency Response Guidebook [16] until qualified technical experts arrive to assist (e.g., CNL and Mutual Aid First Response Teams). Local first responders include fire departments, law-enforcement and/or other provincial or local teams with jurisdiction in the area of the accident.

The CMR will immediately notify the CRL Senior Emergency Officer (SEO). The SEO will determine whether activation of the response plan is required, including the need to establish the Emergency Operations Centers (Emergency Operations Centre, Environmental Assessment Centre, and Site Assessment Centre) and the extent of the initial response required from CNL, such as dispatching CNL response teams and/or mutual aid first response teams.

Upon notification, CNL response team leaders will activate their affiliated emergency team members, as required, for deployment to the accident scene. A trained initial response team will be dispatched to the accident with the staff and equipment listed in table 7.

Table 7: Chalk River Laboratories initial response team staff and equipment

Personnel	Minimum Responders	Available	Equipment
Initial response team leader – Logistics	1	4	First response kits: • protective clothing, respirators, calibrated radiation/contamination instruments • personal dosimeters Emergency trailer: • additional supplies of those listed above • telephone (cell and MSAT, wireless laptop) • weather station • access control supplies • recovery supplies (e.g., spill kit, decontamination equipment)
Communications Representative	As required	2	
Radiation assessment team leader – Health physicist	1	3	
Radiation assessment team members – Radiation surveyors	4	8	
CRL support staff	As required	~100	CRL resources

If the accident involves a CNL shipment, the response team is to:

- provide a rapid initial assessment of the situation
- locate and if required re-establish control and shielding over the source
- assist the on-scene command in establishing response zones
- assist response groups with radiological control, monitoring, and decontamination activities
- conduct recovery operations to return the scene to pre-accident conditions

Where CNL is responsible for decontamination of the accident site, CNL decontamination practices will be employed in the event of the spread of radioactive material onto roadways or flora. Contaminated soil or water removed from the incident area will be transported to CRL for storage. CNL transportation equipment will be used to move vehicles or equipment to and from the accident scene. Radiological and environmental reviews will be conducted to confirm the effectiveness of restoration operations.

Before issuing a transport licence for shipments of HEUNL, CNSC staff will confirm that the ERAP has been approved by Transport Canada and that all regulatory requirements have been met.

4. Overall Conclusion

CNSC staff conclude that the NAC-Legal Weight Truck (NAC-LWT) package proposed by NAC for the transportation of highly enriched uranyl nitrate liquid (HEUNL) from Chalk River Laboratories (CRL) to the U.S. will ensure the protection of the environment and health and safety of people. Prior to the approval of any shipments of HEUNL, CNL must meet all CNSC regulatory requirements.

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