March 2013

NAC-LWT

Legal Weight Truck Cask System

HEUNL RSI Response Package

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC INTERNATIONAL

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Enclosure 1

RSI & Observations Responses
and Supporting References
No. 9225 for NAC-LWT Cask
NAC-LWT SAR, Revision LWT-13B
HEUNL Amendment

Enclosure 1 Contents

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        - 153-109440-REPT-001, Rev. 1 (Proprietary report on low carbon stainless steel interaction with HEUNL solution)
        - V&P Scientific, Chemical Resistance Chart, 2010 (Supporting manufacture document for the use of Teflon material with uranyl nitrate solutions)
        - Kelco Chemical Compatibility Chart, 12/15/2008 (Supporting manufacture documentation for the use of Viton material with uranyl nitrate solutions)
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        - DuPont, "Teflon AF Safety in Handling and Use", 2/98
        - Environmental Working Group, "Teflon Offgas Studies", 5/15/2003

NAC INTERNATIONAL

RESPONSE TO THE

UNITED STATES
NUCLEAR REGULATORY COMMISSION

REQUEST FOR SUPPLEMENTAL INFORMATION

February 2013

FOR REVIEW OF THE CERTIFICATE OF COMPLIANCE NO. 9225, REVISION FOR THE MODEL NO. NAC-LWT PACKAGE TO INCORPORATE HEUNL

(TAC NO. L24708 DOCKET NO. 71-9225)

February 2013

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TO
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STRUCTURAL EVALUATION

2-1 Revise the structural evaluation to show that differential thermal expansion and contraction of the inner containers will not contact the containment boundary.

While the application should discuss differential thermal expansion for normal conditions of transport and hypothetical accident conditions, the application should also show that there will not be any contact between the containment boundary and the high-enriched uranyl nitrate liquid (HEUNL) inner container that would challenge the package's containment for thermal expansion of the inner container and contraction of the containment boundary during evaluation of the cold test.

This information is needed to demonstrate compliance with Title 10 *Code of Federal Regulations* (10 CFR) 71.51 (a)(1) and (2).

NAC International Response to Structural Evaluation RSI 2-1:

NAC Proprietary Calculation 65008500-2010, "Canister Structural Evaluations for HEUNL in the NAC-LWT", has been revised to confirm that the thermal expansion of the HEUNL containers does not result in closure of the axial or radial gaps relative to the cask body inner shell. The clearances between the containers and the inner shell were evaluated for the bounding conditions, which are the freezing of the liquid at -40°F ambient as well as the maximum temperatures obtained in the fire accident condition. SAR Section 2.6.12.13.2 and Section 2.7.7.15.2 were revised to include the conclusion that interference due to thermal expansion does not occur for normal or accident conditions of transport.

NAC INTERNATIONAL RESPONSE
TO
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MATERIALS EVALUATION

2-2 Provide data that there are no significant chemical, galvanic, or other reactions between the uranyl nitrate solution and its constituents and either the steel HEUNL inner container or its o-ring seals on the port valve covers. The analysis should include the potential generation of hydrogen from chemical reactions and radiological interactions.

No information addressing the interaction of the uranyl nitrate with the packaging components was found in the application.

This information is needed to demonstrate compliance with 10 CFR 71.43(d).

NAC International Response to Materials Evaluation RSI 2-2:

[redacted]

Since there are no significant chemical or galvanic reactions, there will be no significant hydrogen production during transport outside of any being produced via radiolysis. With respect to hydrogen being produced via radiolysis, the solution to be transported contains no significant neutron or alpha sources (see Section 5.3.20 of the NAC-LWT SAR). Gamma hydrogen production is discussed in the context of the pressure section added as a response to RSI 3-2.

NAC INTERNATIONAL RESPONSE
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THERMAL EVALUATION

3-1 Revise the application to ensure that the pressure within the containment boundary and the HEUNL container is based on the most bounding pressure considering the hot and cold tests for normal conditions of transport. In addition, for completeness, provide the pressure inside an empty HEUNL container during the fire test for hypothetical accident conditions. Also, provide the design pressure limit for the HEUNL container.

The staff needs to ensure that pressure created from any of the tests for normal conditions of transport and hypothetical accident conditions within the containment boundary and within the HEUNL containers have been evaluated and are discussed in the application and are completely summarized in Chapter 3 of the safety analysis report (SAR). The application did not appear to provide an analysis of the pressure inside the containment boundary and the HEUNL container for the cold test required for evaluations of normal conditions of transport. The pressure on the HEUNL container from the frozen HEUNL that has expanded during the cold test was not addressed. The pressure inside the containment boundary may increase due to a decrease of the available volume inside the containment boundary due to both expansion of the HEUNL inner containers and thermal contraction of the containment boundary of the package.

The application does not appear to address the pressure inside an empty HEUNL container during hypothetical accident conditions or provide the design pressure limit for the HEUNL container.

This information is needed to demonstrate compliance with 10 CFR 71.51.

NAC International Response to Thermal Evaluation RSI 3-1:

As discussed in the response to RSI 3-2, new sections were created in Chapter 3 and 4 to address various pressurization information requests. Included in the Chapter 3, Sections 3.4.4.9 and 3.5.4.8, are maximum pressures for the empty container under normal and accident conditions (bounding maximum temperature). SAR Section 4.5.6 contains the gas generation discussion that leads to a 100 psig maximum normal condition pressure in the container. The cask containment pressure listed in Chapter 3, Sections 3.4.4.9 and 3.5.4.8, uses the maximum normal and accident condition temperatures with the maximum expansion allowed for the containers under cold conditions, which is conservative. Container pressure calculations are based on the container dimensions and maximum fill. Contraction of the containment boundary does not significantly affect the free volume in the cask cavity. However, the change was considered in the calculation.

NAC International Response to Thermal Evaluation RSI 3-1 (cont'd):

SAR Section 8.1.4.4 defines a hydrostatic test pressure of 150 psig maximum, which is based on a design pressure of 112 psig (10 (for gauge tolerance) + 1.25 × 112 = 150 psig). The structural evaluation for the maximum pressure of 150 psig is performed in SAR Section 2.6.12.13.2. The loading applied to the HEUNL container due to freezing expansion of the HEUNL liquid was presented in SAR Section 2.6.12.13.2. It has been revised to reflect a condition where the containers were subjected to two shipments in which full freezing occurred in both shipments. The 150 psig is also shown to bound the maximum pressure due to the fire accident condition identified in SAR Section 3.5.4.8.2.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

THERMAL EVALUATION

3-2 Revise the application to ensure the pressure calculations for both normal conditions of transport and hypothetical accident conditions consider all possible sources of gases, such as those gases initially present in the package; saturated vapor, including water vapor from the contents or packaging; helium from the radioactive decay of the contents; and hydrogen or other gases resulting from thermal or radiation induced decomposition of materials such as water or plastics. Also, demonstrate that hydrogen and other flammable gases comprise less than 5% by volume of the total gas inventory within any confined volume.

The application does not appear to address the impact on the maximum normal operation pressure (MNOP) and the pressure within the cask cavity (for normal conditions of transport and hypothetical accident conditions), and within the HEUNL containers from all possible sources. The application also does not appear to show that hydrogen or other flammable gases comprise less than 5% by volume of the total gas inventory within any confined volume.

This information is needed to demonstrate compliance with 10 CFR 71.33(b)(5) and 71.43(d).

NAC International Response to Thermal Evaluation RSI 3-2:

In response to RSI Observation 3-2, SAR Sections 3.4.4.9 (normal) and 3.5.4.8 (accident) were created to address pressure within the container and containment boundary either by specifically addressing the pressure or to point to other locations within the SAR for pressure related input. SAR Section 4.5.6 (new) has been added to the SAR to address both container pressure and hydrogen generation/volume fraction.

Cask Cavity / Containment Boundary

The cask cavity is evacuated and backfilled with helium as described in Chapter 7, Operations. No significant quantity of water vapor will remain in the cask cavity after this procedure. The containers are tested to assure that the quick disconnects are closed and do not release material (also a container lid containing seals is installed). The containers are evaluated to survive both normal and accident conditions without a release of liquid. The container rails have been revised to include a thermally stable material (Teflon) and under no operating conditions will they significantly off-gas. Teflon is damaged by radiation via chain scission. However, this process does not generate significant gas quantities (this effect is also limited without air/oxygen present and the cask cavity is inerted for transport). Effects on the cask pressure when dimensional changes of the container occur due to an HEUNL content phase change (i.e. "freezing") are addressed in the new Chapter 3 Sections 3.4.4.9 and 3.5.4.8.

NAC International Response to Thermal Evaluation RSI 3-2 (cont'd):

Container

Pressurization of the container due to hydrogen and oxygen generation is discussed in the SAR Section 4.5.6 (new section). This section also addresses hydrogen content. The solution does not contain any significant quantity of unstable actinides (see Chapter 5) and therefore does not generate any significant gas quantities from alpha decay or neutron reactions.

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THERMAL EVALUATION

3-3 Provide the ANSYS thermal input and output files for normal conditions of transport.

The ANSYS thermal input and output files for normal conditions of transport are necessary in order to verify the modeling assumptions and the results shown in the application. The staff specifically prefers text-based files with an appropriate level of comments to allow for a timely technical review.

This information is needed to demonstrate compliance with 10 CFR 71.71.

NAC International Response to Thermal Evaluation RSI 3-3:

Section 3(b) of Enclosure 1 in the HEUNL RSI submittal package is one data disk containing the ANSYS thermal input and output files for normal conditions of transport.

NAC INTERNATIONAL RESPONSE
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CONTAINMENT EVALUATION

4-1 Confirm that HEUNL will not be released from HEUNL containers during normal and accident conditions, or, confirm the integrity of the containment boundary if there were a release from the HEUNL containers into the Model No. NAC-LWT packaging.

Page 4.1-1 (and 7.1-1) states that no release of material from HEUNL containers is expected [emphasis added] under normal conditions of transport and hypothetical accident conditions. Analyses that confirm HEUNL will not be released from the four HEUNL containers located within the Model No. NAC-LWT packaging during normal conditions of transport and hypothetical accident conditions should be provided. Otherwise, specify the temperatures, pressures, and stresses that would exist during normal conditions of transport and hypothetical accident conditions if the HEUNL were in direct contact with the containment boundary to confirm the integrity of the containment boundary.

This information is needed to demonstrate compliance with 10 CFR 71.43, 71.71, and 71.73.

NAC International Response to Containment Evaluation RSI 4-1:

[redacted]

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

CONTAINMENT EVALUATION

4-2 Clarify that the interaction between the HEUNL container payload and NAC LWT packaging is bounded by previous NAC LWT payloads.

Considering this amendment request is for a new HEUNL payload arrangement, it should be clarified that the interaction between the HEUNL container payload and NAC LWT packaging is bounded by previous NAC LWT payloads, thereby confirming the integrity of the containment boundary during NCT and HAC.

This information is needed to demonstrate compliance with 10 CFR 71.71, 71.73.

NAC International Response to Containment Evaluation RSI 4-2:

The containment boundary components potentially affected by the HEUNL payload are the cask lid (bolts and seals), ports (bolts and seals), cask inner shell and bottom forging. SAR Sections 4.2.2 and 4.3.2.3 contain the maximum containment pressure for normal and accident conditions, respectively. The values in these sections demonstrate that the maximum containment pressures generated by the HEUNL payload are bounded by previously evaluated contents. SAR Chapter 3 Sections 3.4.4.9 and 3.5.4.8 were added to include maximum normal and accident condition containment pressures to justify the values in SAR Chapter 4. SAR Chapter 3 analysis is based on the HEUNL solution being retained within the container under all conditions. This consideration is consistent with the evaluation of the containers in SAR Chapter 2, which confirms that the HEUNL container boundary is maintained for all normal and accident conditions.

The HEUNL payload is approximately 2,100 pounds as compared to the LWT design basis payload of 4,000 pounds. Therefore, the pressure load on the cask lid, cask lid bolts, cask inner shell and bottom forging are less than those of previously evaluated contents. Therefore, the addition of the HEUNL containers, as payload, does not require any new evaluations for containment boundary components.

NAC INTERNATIONAL RESPONSE
TO
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CRITICALITY EVALUATION

6-1 Provide the necessary input files so that staff may complete its review of the criticality analysis for the application.

The applicant only provided one input for the SAR. Due to the ambiguity with the geometric terms used to define the criticality models and the corresponding figures in the application (see criticality evaluations observation 1 in Enclosure 2), the staff is unclear as to what was actually modeled. As such, the staff cannot determine whether the design of the Model No. NAC-LWT package has been appropriately represented in the criticality models.

This information is needed to demonstrate compliance with 10 CFR 71.31.

NAC International Response to Criticality Evaluation RSI 6-1:

Criticality input files are provided in the Section 3(c) of Enclosure 1 to the HEUNL RSI submittal package. As a result of responding to the RSI observations, the SAR text in Chapter 6 has been revised to clarify the configurations.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

CRITICALITY EVALUATION

6-2 Either provide an analysis that evaluates the configuration where uranyl nitrate fills the cavity between the HEUNL container and the inner shell of containment boundary or provide assurance prior to shipment that each HEUNL inner container is positively closed and will not leak.

The applicant models the cavity as dry or flooded with water, but does not consider the possibility of uranyl nitrate filling the cavity volume. By analyzing this possibility, the applicant should cover the situation of a container leaking.

As stated in Section 6.7.2.3, "Criticality Calculations," under 10 CFR 71.55 Scoping Calculation:

"Initial scoping analysis evaluates cask interior flooding conditions. Due to the system containing little cavity volume for moderation, flooding conditions have negligible effects on reactivity. Normal and accident configuration casks are expected and are confirmed to be similar from a neutronics perspective."

This information is needed to demonstrate compliance with 10 CFR 71.55(b).

NAC International Response to Criticality Evaluation RSI 6-2:

SAR Chapter 7, Section 7.1.13, "Procedure for loading HEUNL into the NAC-LWT cask," has been revised to include testing, via Step 13, of container closure prior to transport and after filling with solution. Performance of this loading procedure provides assurance that the container quick disconnects and bolted closure lid are positively closed prior to shipment and will not leak.

NAC INTERNATIONAL RESPONSE
TO
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THERMAL EVALUATION (PROPRIETARY)

3-1P [redacted]

<u>NAC International Response to Thermal Evaluation RSI 3-1P:</u>

[redacted]

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION

THERMAL EVALUATION (PROPRIETARY)

3-2P [redacted]

<u>NAC International Response to Thermal Evaluation RSI 3-2P:</u>

[redacted]

NAC INTERNATIONAL

RESPONSE TO THE

UNITED STATES
NUCLEAR REGULATORY COMMISSION

REQUEST FOR SUPPLEMENTAL INFORMATION

OBSERVATIONS

February 2013

FOR REVIEW OF THE CERTIFICATE OF COMPLIANCE NO. 9225, REVISION FOR THE MODEL NO. NAC-LWT PACKAGE TO INCORPORATE HEUNL

(TAC NO. L24708 DOCKET NO. 71-9225)

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THERMAL EVALUATION

3-1 OBS To assist the staff review, revise Chapter 3 of the SAR to provide summaries, or references to other sections within the SAR that address the MNOP and other pressures within the containment boundary and HEUNL containers during the tests for normal conditions of transport and hypothetical accident conditions pressure. Revise Chapter 3 of the SAR to provide summaries or references to other sections within the SAR that address thermal stresses of the HEUNL containers and the cask cavity during normal conditions of transport and hypothetical accident conditions.

If this information has been provided in calculation packages, or in other sections of the SAR, it should be summarized or referenced in Chapter 3 of the SAR. The staff needs to ensure that normal conditions of transport and hypothetical accident conditions pressures and thermal stresses within the cask cavity and within the HEUNL containers have been evaluated and are discussed in the SAR and are completely summarized in Chapter 3 of the SAR.

This information is needed to demonstrate compliance with 10 CFR 71.51(a)(1) and (2).

NAC International Response to Thermal Evaluation RSI Observation 3-1 OBS:

SAR Sections 3.4.4.9 (normal) and 3.5.4.8 (accident) have been added to address pressure within the HEUNL container and LWT containment boundary either by specifically addressing the pressure or to point to other locations within the SAR for pressure related input.

The thermal stresses are evaluated in SAR Section 2.6.12.13.2 along with the other loadings associated with the normal conditions of transport. Due to the low heat load, the thru wall thermal gradient is sufficiently small to neglect thermal stresses due to the heat load. The most significant stresses due to thermal expansion are those arising from the liquid HEUNL freezing for the cold condition. To ensure that the bounding condition is considered, the freezing is considered to occur for two shipments, in which the same container is subjected to being filled, frozen, thawed, drained, refilled (to the larger volume container volume created by the first freeze) and then subjected to an additional freezing event.

Accident conditions for the HEUNL container are evaluated in SAR Section 2.7.7.15. Thermal stresses are not evaluated for the accident condition under ASME Section III, Subsection NB. However, the pressure due to the HEUNL being maintained as a liquid is evaluated as a primary stress.

NAC INTERNATIONAL RESPONSE
TO
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THERMAL EVALUATION

3-2 OBS Discuss any impact on pressures and stresses for the HEUNL containers and the containment boundary due to the HEUNL content temperature exceeding the boiling point during the thermal hypothetical accident conditions.

The maximum predicted HEUNL content temperature during hypothetical accident conditions given in Section 3.5.3.16 of the SAR is 296°F. The boiling point for a diluted mixture of HEUNL given in Section 4.2.2 of the SAR is 100°C (212°F.) The application did not address the impact on pressures and stresses for the HEUNL containers and the containment boundary due to the contents exceeding the boiling point during the thermal test for hypothetical accident conditions.

This information is needed to demonstrate compliance with 10 CFR 71.33(b)(5), 71.43(d), and 71.51(a)(2).

<u>NAC International Response to Thermal Evaluation RSI Observation 3-2 OBS:</u>

[redacted]

NAC INTERNATIONAL RESPONSE
TO
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CONTAINMENT EVALUATION

4-1 OBS Provide a sketch showing the extent of the containment boundary, including lid/O-ring, vent, and drain port covers/O-rings, etc.

Chapter 1 and 4 of the consolidated application dated June 18, 2010, briefly describes different O-rings as part of the package. However, details of the containment boundary are often unclear, such as where and when tetrafloroetheylene (TFE) O-rings are used (see page 4.1-1 of the SAR). A sketch showing the extent of the entire containment boundary would be helpful in understanding the containment boundary.

This information is needed to demonstrate compliance with 10 CFR 71.31, 71.33.

NAC International Response to Containment Evaluation RSI Observation 4-1 OBS:

SAR Chapter 4 has been revised to include Figure 4.1-1 to illustrate the containment boundary. Text referring to this figure has been added to SAR Section 4.1.

NAC INTERNATIONAL RESPONSE
TO
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CRITICALITY EVALUATION

6-1 OBS Clarify how the words "interior" and "exterior" are used to explain moderator and reflector conditions for cask array analysis.

The applicant writes in Section 6.7.2.3, "Criticality Calculations," paragraph 3:

"After the single cask analysis is complete, cask array analysis is performed to meet 10 CFR 71.59 requirements. Per the standard review plan (NUREG-1617) the 10 CFR 71.59 requirements are met by evaluating a cask array with dry interior and exterior for normal condition and optimum interior and exterior moderated array for accident conditions (see Sections 6.5.5 and 6.5.6 in NUREG-1617)."

The part about a cask array with dry exterior is not correct, since the model is performed with close reflection on all sides of the array per the requirements in 10 CFR 71.59(a), unless the array is infinite as discussed in Section 6.5.5 of NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel." The applicant states that the array is infinite later in the section, but the wording in the paragraph above should be rewritten to be consistent with what is stated in NUREG-1617 and 10 CFR 71.59.

This information is needed to demonstrate compliance with 10 CFR 71.7(a).

<u>NAC International Response to Criticality Evaluation RSI Observation 6-1 OBS:</u>

The paragraph has been revised to clarify that exterior moderator refers to the cask exterior (i.e. material between casks and not the exterior of the stack (array) that is referred to by 10 CFR 71.59, which must be fully water reflected). A text addition has also been made to state that this particular array (HEUNL) will be evaluated in an infinite array configuration and therefore cask array (cask stack) exterior moderation is not applicable.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION – OBSERVATION

CRITICALITY EVALUATION

6-2 OBS Explain the use of a 20 cm water reflector to produce full reflection by water on all sides of the package.

The applicant writes in Section 6.7.2.3, "Criticality Calculations," under <u>10 CFR 71.55 Scoping Calculation:</u>

"In compliance with 10 CFR 71.55 the scoping calculations are based on a single cask with a 20 cm boundary from the cask exterior dimensions. The space between cask and boundary is flooded with full density water to produce a fully water reflected system."

Full water reflection is defined as reflection by water of 30 cm. Unless the 20 is a typo, it would seem that the applicant used the 20 cm definition from 71.55(f)(1), which is for transport of fissile material packages by air.

This information is needed to demonstrate compliance with 10 CFR 71.55.

<u>NAC International Response to Criticality Evaluation RSI Observation 6-2 OBS:</u>

A 20-cm water reflector is the basis for the evaluations previously provided. It is not based on 71.55(f)(1). Based on a migration length of a fission neutron in full density water in the range of 6 cm, a 20-cm reflector (3 times migration length) is more than sufficient to achieve full reflection. The 20-cm value is also consistent with other payload evaluations in the NAC-LWT SAR.

To address the "definition of 30 cm" the bounding analysis for each of the water reflected conditions (10 CFR 71.55) was re-evaluated using a 30-cm reflector. The new cases are summarized in a new subsection to SAR Section 6.7.2.3. This section demonstrates that there is no statistically significant effect of a revision from 20 to 30-cm.

The revised cases, in addition to addressing the 30-cm reflector, also include a slight revision to the container model. To provide additional clearance for expansion of the container, the lower section (stand-off) was reduced in height by 0.19 inch. While not changing fissile material quantity/volume of the container, this change has the potential of increasing system reactivity by increasing neutron interaction between containers. As demonstrated in the revised SAR text, there is no statistically significant effect on the system as a result of reflector thickness increase and spacing modification.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION – OBSERVATION

CRITICALITY EVALUATION

6-3 OBS Identify the method used to ensure that the density limit of 7.2 g ^{235}U/L for HEUNL containers will not be exceeded.

The applicant states that fissile material in the package is limited to a density of 7.2 g^{235}U/L in Table 1.2.3-14 and Sections 6.1 and 6.7.2.1 of the SAR. However, Chapter 7, "Operating Procedures" does not state how this limit will be ensured.

Also, ensure consistent units within the application for the density limit of 7.2 g ^{235}U/L. The units are listed as g U/L in Table 1.2.3-14 of the SAR, but should be g ^{235}U/L (or g/L ^{235}U) as stated in Section 1.2.3.12 and elsewhere in the SAR.

This information is needed to demonstrate compliance with 10 CFR 71.55 and 71.59.

NAC International Response to Criticality Evaluation RSI Observation 6-3 OBS:

SAR Chapter 7, Section 7.1.13, step number 16 of the loading procedure contains the following statement:

"16. Verify that the HEUNL container contents and loading arrangement comply with the content type, form, heat load and quantity conditions of the NAC-LWT CoC."

This section will ensure that all CoC limits are to be met. To enhance visibility of the criticality requirement, this section has been modified to specifically include the limitation on fissile material quantity. Additional text states:

"Assure fissile material in the package is limited to a density of 7.2 g^{235}U/L."

Table 1.2.3-14 has been revised to 7.2 g ^{235}U/L. Note that the content limitation in the table states "Maximum ^{235}U content" making the quantity "g ^{235}U/L" a somewhat duplicate specification.

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION – OBSERVATIONS

MATERIALS EVALUATION (PROPRIETARY)

2-1P OBS [redacted]

NAC International Response to Materials Evaluation RSI Observation 2-1P OBS:

[redacted]

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR SUPPLEMENTAL INFORMATION – OBSERVATIONS

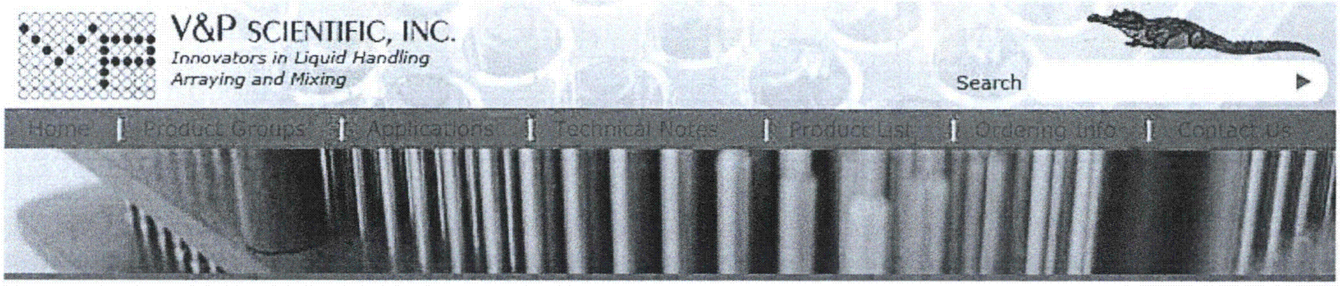
CRITICALITY EVALUATION (PROPRIETARY)

6-1P OBS [redacted]

NAC International Response to Criticality Evaluation RSI Observation 6-1P OBS:

[redacted]

PROPRIETARY INFORMATION REMOVED
153-109440-REPT-001, Rev. 1
WITHHELD IN ITS ENTIRETY PER 10 CFR 2.390



Chemical Resistance Chart

Resistance	Material
E = Excellent **G** = Good **F** = Fair **N** = Not Recommended	**PTFE** = Polytetrafluoroethylene including of Teflon® **SS** = Stainless Steel (316) **PE#1** = Convenional Polyethylene **PE#2** = Rigid Polyethylene **PP** = Polypropylene **PVC** = Polyvinylchloride

This information, based on experience to date, is believed to be reliable. It is intended as a guide for use at your own discretion and risk. All indications refer to room temperature.

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Acetaldehyde	E	E	G	G	G	G
Acetamide	E	E	E	E	E	N
Acetic Acid, 5%	E	E	E	E	E	E
Acetic Acid, 50%	E	E	E	E	E	E
Acetone	E	E	E	E	E	E
Aluminum Hydroxide	E	E	E	E	E	E
Ammonia	E	E	E	E	E	E
Ammonium Hydroxide	E	E	E	E	E	E
Ammonium Oxalate	E	E	E	E	E	E
n-Amyl Acetate	E	E	G	E	G	F
Amyl Chloride	E	--	N	F	N	N
Aniline	E	E	E	E	G	N

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Benzaldehyde	E	--	E	E	E	N
Benzene	E	E	F	G	G	N
Benzoic Acid, Sat.	E	E	E	E	E	E
Benzyl Acetate	E	--	E	E	E	F
Boric Acid	E	F	E	E	E	E
Bromine	E	N	N	F	N	G
Bromobenzene	E	--	N	F	N	F
n-Butyl Acetate	E	F	G	E	G	N
sec-Butyl Alcohol	E	--	E	E	E	G
Butyric Acid	E	E	N	F	N	G

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Calcium Hypochlorite	E	F	E	E	E	G
Carbazole	E	--	E	E	E	N
Carbon Disulfide	E	E	N	N	E	N
Carbon Tetrachloride	E	G	F	G	G	G
Chlorine	E	G	G	G	G	E
Chloroacetic Acid	E	F	E	E	E	F
Chloroform	E	E	F	G	G	N
Chromic Acid	E	G	E	E	E	E
Citric Acid	E	E	E	E	E	G
Cresol	E	E	N	F	E	N

Cyclohexane	E	E	G	E	G	G

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Decalin	E	--	G	E	G	E
o-Dichlorobenzene	E	--	F	F	F	G
p-Dichlorobenzene	E	--	F	G	E	N
Diethyl Benzene	E	--	N	F	N	N
Diethyl Ether	E	--	N	F	N	F
Diethyl Ketone	E	--	G	G	G	N
Diethyl Malonate	E	--	E	E	E	G
Dimethyl Formamide	E	--	E	E	E	F

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Ether	E	E	N	F	N	F
Ethyl Acetate	E	E	E	E	E	F
Ethyl Benzene	E	--	F	G	F	N
Ethyl Benzoate	E	--	F	G	G	N
Ethyl Butyrate	E	--	G	G	G	N
Ethyl Chloride, Liquid	E	E	F	G	F	N
Ethyl Cyanoacetate	E	--	E	E	E	NF
Ethyl Lactate	E	--	E	E	E	F
Ethylene Chloride	E	E	G	G	G	N
Ethylene Glycol	E	E	E	E	E	E
Ethylene Oxide	E	--	F	G	F	F

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Fluorine	G	--	F	G	G	N
Formic Acid, 50%	E	F	E	E	E	G
Formic Acid, 90-100%	E	N	E	E	E	F
Fuel Oil	E	E	F	G	E	E
Gasoline	E	E	F	G	E	G
Glycerine	E	E	E	E	E	E

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
n-Heptane	E	E	F	G	E	F
Hexane	E	E	N	G	E	G
Hydrochloric Acid, 1-5%	E	N	E	E	E	E
Hydrochloric Acid, 35%	E	N	E	E	E	G
Hydrofluoric Acid, 4%	E	N	E	E	E	G
Hydrofluoric Acid, 48%	E	N	E	E	E	G
Hydrogen	E	--	E	E	E	E
Hydrogen Peroxide	E	F	E	E	E	E

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Isopropyl Acetate	E	--	G	E	G	N
Isopropyl Benzene	E	--	F	G	F	N
Kerosene	E	E	F	G	G	E
Lactic Acid, 3%	E	G	E	E	E	G
Lactic Acid, 85%	E	F	E	E	E	G

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Magnesium Salts	E	G	E	E	E	E
Methoxyethyl Oleate	E	--	E	E	E	N
Methyl Ethyl Ketone	E	E	E	E	E	N
Methyl Isobutyl Ketone	E	E	G	E	G	N
Methyl Propyl Ketone	E	--	G	E	G	N
Methylene Chloride	E	E	F	G	F	N

Chemical	PTFE	SS	PE#1	PE#2	PP	PVC
Nitric Acid, 50%	E	G	E	G	G	G
Nitric Acid, 70%	E	N	E	G	G	F
Nitrobenzene	E	E	F	G	F	N
n-Octane	E	--	E	E	E	F

Orange Oil	E	--	F	G	G	F
Chemical	**PTFE**	**SS**	**PE#1**	**PE#2**	**PP**	**PVC**
Perchloric Acid	E	--	G	G	G	G
Perchloroethylene	E	E	N	N	N	N
Phenol, Crystals	E	E	G	G	G	F
Phosphoric Acid, 1-5%	E	E	E	E	E	E
Phosphoric Acid, 85%	E	G	E	E	E	E
Potassium Hydroxide	E	G	E	E	E	E
Propane Gas	E	E	N	F	N	E
Propylene Glycol	E	E	E	E	E	F
Propylene Oxide	E	--	E	E	E	F
Chemical	**PTFE**	**SS**	**PE#1**	**PE#2**	**PP**	**PVC**
Resorcinol	E	--	E	E	E	F
Salicylaldehyde	E	--	E	E	E	F
Sulfuric Acid, 1-6%	E	F	E	E	E	E
Sulfuric Acid, 20%	E	N	E	E	E	E
Sulfuric Acid, 60%	E	N	E	E	E	E
Sulfuric Acid, 98%	E	N	E	E	E	N
Sulfur Dioxide, Liq.	E	E	N	F	N	F
Sulfur Salts	E	E	F	G	F	N
Chemical	**PTFE**	**SS**	**PE#1**	**PE#2**	**PP**	**PVC**
Tartaric Acid	E	G	E	E	E	E
Tetrahydrofuran	E	E	F	G	G	N
Thionyl Chloride	E	--	N	N	N	N
Toluene	E	E	F	G	G	F
Trichloroethane	E	E	N	F	N	N
Trichloroethylene	E	E	N	F	N	N
Turpentine	E	E	F	G	G	G
Vinylidene Chloride	E	--	N	F	N	N
Xylene	E	E	G	G	F	N
Zinc Salts/Stearate	E	G	E	E	E	E

Table courtesy of
JENSEN INERT PRODUCTS, INC.

KELCO

CHEMICAL COMPATIBILITY CHART

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Our products can be exposed to a huge variety of chemicals. The data table below is an application guide, and indicates the resistance of the specific thermoplastics we use in the construction of our products, to common chemicals.

The data given should be used cautiously, and as a guide only. Various factors such as concentration, additives, exposure time, temperature and internal mechanical stress levels will all impact on the working life of our plastic parts.

Use the table conservatively and if any doubt exists, do not proceed with the application.

In the table below there are four ratings:

- **A-Excellent** indicates that at ambient temperature and pressure, the material should not be affected.
- **B-Good** indicates that the material is slightly affected but not to the point of being unsuitable.
- **C-Fair** indicates a degree of reaction that is generally considered unsuitable and should not be used.
- **D-Severe Effect** indicates that the material should not be used under any circumstances

All ratings are taken from data measured at ambient temperature and pressure.

CHEMICAL	COMPATIBILITY
Acetaldehyde	D-Severe Effect
Acetamide	B-Good
Acetate Solvent	D-Severe Effect
Acetic Acid	B-Good
Acetic Acid 20%	B-Good
Acetic Acid 80%	B-Good
Acetic Acid, Glacial	D-Severe Effect
Acetic Anhydride	D-Severe Effect
Acetone	D-Severe Effect
Acetyl Chloride (dry)	A-Excellent
Acetylene	A-Excellent
Acrylonitrile	D-Severe Effect
Adipic Acid	A-Excellent
Alcohols:Amyl	A-Excellent
Alcohols:Benzyl	A-Excellent
Alcohols:Butyl	A-Excellent
Alcohols:Diacetone	D-Severe Effect
Alcohols:Ethyl	A-Excellent
Alcohols:Hexyl	C-Fair
Alcohols:Isobutyl	A-Excellent
Alcohols:Isopropyl	A-Excellent
Alcohols:Methyl	C-Fair
Alcohols:Octyl	B-Good
Alcohols:Propyl	A-Excellent
Aluminum Chloride	A-Excellent
Aluminum Chloride 20%	A-Excellent
Aluminum Fluoride	A-Excellent
Aluminum Hydroxide	A-Excellent
Aluminum Nitrate	A-Excellent
Aluminum Potassium Sulfate 10%	A-Excellent
Aluminum Potassium Sulfate 100%	A-Excellent
Aluminum Sulfate	A-Excellent
Alums	A-Excellent
Amines	D-Severe Effect
Ammonia 10%	D-Severe Effect
Ammonia Nitrate	D-Severe Effect
Ammonia, anhydrous	D-Severe Effect
Ammonia, liquid	D-Severe Effect
Ammonium Acetate	A-Excellent
Ammonium Bifluoride	A-Excellent
Ammonium Carbonate	A-Excellent
Ammonium Chloride	A-Excellent
Ammonium Hydroxide	B-Good
Ammonium Nitrate	A-Excellent
Ammonium Persulfate	A-Excellent

Ammonium Phosphate, Dibasic	A-Excellent
Ammonium Phosphate, Monobasic	A-Excellent
Ammonium Phosphate, Tribasic	A-Excellent
Ammonium Sulfate	A-Excellent
Ammonium Sulfite	D-Severe Effect
Amyl Acetate	D-Severe Effect
Amyl Alcohol	A-Excellent
Amyl Chloride	B-Good
Aniline	A-Excellent
Aniline Hydrochloride	A-Excellent
Antifreeze	A-Excellent
Antimony Trichloride	A-Excellent
Aqua Regia (80% HCl, 20% HNO3)	B-Good
Arochlor 1248	A-Excellent
Aromatic Hydrocarbons	A-Excellent
Arsenic Acid	A-Excellent
Arsenic Salts	A-Excellent
Asphalt	A-Excellent
Barium Carbonate	A-Excellent
Barium Chloride	A-Excellent
Barium Cyanide	A-Excellent
Barium Hydroxide	A-Excellent
Barium Nitrate	A-Excellent
Barium Sulfate	A-Excellent
Barium Sulfide	A-Excellent
Beer	A-Excellent
Beet Sugar Liquids	A-Excellent
Benzaldehyde	D-Severe Effect
Benzene	A-Excellent
Benzene Sulfonic Acid	A-Excellent
Benzoic Acid	A-Excellent
Benzol	A-Excellent
Benzyl Chloride	A-Excellent
Bleaching Liquors	A-Excellent
Borax (Sodium Borate)	A-Excellent
Boric Acid	A-Excellent
Brewery Slop	A-Excellent
Bromine	A-Excellent
Butadiene	B-Good
Butane	A-Excellent
Butanol (Butyl Alcohol)	A-Excellent
Butter	A-Excellent
Buttermilk	A-Excellent
Butyl Amine	D-Severe Effect
Butyl Ether	D-Severe Effect
Butyl Phthalate	C-Fair
Butylacetate	D-Severe Effect

Butylene	A-Excellent
Butyric Acid	B-Good
Calcium Bisulfide	A-Excellent
Calcium Bisulfite	A-Excellent
Calcium Carbonate	A-Excellent
Calcium Chlorate	A-Excellent
Calcium Chloride	A-Excellent
Calcium Hydroxide	A-Excellent
Calcium Hypochlorite	A-Excellent
Calcium Nitrate	A-Excellent
Calcium Oxide	B-Good
Calcium Sulfate	A-Excellent
Calgon	A-Excellent
Cane Juice	A-Excellent
Carbolic Acid (Phenol)	A-Excellent
Carbon Bisulfide	A-Excellent
Carbon Dioxide (dry)	B-Good
Carbon Dioxide (wet)	B-Good
Carbon Disulfide	A-Excellent
Carbon Monoxide	A-Excellent
Carbon Tetrachloride	A-Excellent
Carbon Tetrachloride (dry)	A-Excellent
Carbonated Water	A-Excellent
Carbonic Acid	A-Excellent
Catsup	A-Excellent
Chlorinated Glue	A-Excellent
Chlorine (dry)	A-Excellent
Chlorine Water	A-Excellent
Chlorine, Anhydrous Liquid	A-Excellent
Chloroacetic Acid	D-Severe Effect
Chlorobenzene (Mono)	A-Excellent
Chlorobromomethane	A-Excellent
Chloroform	A-Excellent
Chlorosulfonic Acid	D-Severe Effect
Chocolate Syrup	A-Excellent
Chromic Acid 10%	B-Good
Chromic Acid 30%	A-Excellent
Chromic Acid 5%	A-Excellent
Chromic Acid 50%	A-Excellent
Cider	A-Excellent
Citric Acid	A-Excellent
Citric Oils	A-Excellent
Cloroxr (Bleach)	A-Excellent
Coffee	A-Excellent
Copper Chloride	A-Excellent
Copper Cyanide	A-Excellent
Copper Fluoborate	A-Excellent

Copper Nitrate	A-Excellent
Copper Sulfate >5%	A-Excellent
Copper Sulfate 5%	A-Excellent
Cream	A-Excellent
Cresols	A-Excellent
Cresylic Acid	A-Excellent
Cupric Acid	A-Excellent
Cyanic Acid	A-Excellent
Cyclohexane	A-Excellent
Cyclohexanone	D-Severe Effect
Detergents	A-Excellent
Diacetone Alcohol	D-Severe Effect
Dichlorobenzene	C-Fair
Dichloroethane	C-Fair
Diesel Fuel	A-Excellent
Diethyl Ether	D-Severe Effect
Diethylamine	A-Excellent
Diethylene Glycol	A-Excellent
Dimethyl Aniline	D-Severe Effect
Dimethyl Formamide	C-Fair
Diphenyl	A-Excellent
Diphenyl Oxide	A-Excellent
Dyes	A-Excellent
Epsom Salts (Magnesium Sulfate)	A-Excellent
Ethane	A-Excellent
Ethanol	A-Excellent
Ethanolamine	D-Severe Effect
Ether	C-Fair
Ethyl Acetate	D-Severe Effect
Ethyl Benzoate	A-Excellent
Ethyl Chloride	A-Excellent
Ethyl Ether	D-Severe Effect
Ethyl Sulfate	A-Excellent
Ethylene Bromide	A-Excellent
Ethylene Chloride	B-Good
Ethylene Chlorohydrin	A-Excellent
Ethylene Diamine	B-Good
Ethylene Dichloride	A-Excellent
Ethylene Glycol	A-Excellent
Ethylene Oxide	D-Severe Effect
Fatty Acids	A-Excellent
Ferric Chloride	A-Excellent
Ferric Nitrate	A-Excellent
Ferric Sulfate	A-Excellent
Ferrous Chloride	A-Excellent
Ferrous Sulfate	B-Good
Fluoboric Acid	B-Good

Fluorine	C-Fair
Fluosilicic Acid	B-Good
Formaldehyde 100%	D-Severe Effect
Formaldehyde 40%	A-Excellent
Formic Acid	C-Fair
Freon 113	B-Good
Freon 12	B-Good
Freon 22	D-Severe Effect
Freon TF	B-Good
Freonr 11	B-Good
Fruit Juice	A-Excellent
Fuel Oils	A-Excellent
Furan Resin	D-Severe Effect
Furfural	D-Severe Effect
Gallic Acid	A-Excellent
Gasoline (high-aromatic)	A-Excellent
Gasoline, leaded, ref.	A-Excellent
Gasoline, unleaded	A-Excellent
Gelatin	A-Excellent
Glucose	A-Excellent
Glue, P.V.A.	B-Good
Glycerin	A-Excellent
Glycolic Acid	A-Excellent
Gold Monocyanide	A-Excellent
Grape Juice	A-Excellent
Grease	A-Excellent
Heptane	A-Excellent
Hexane	A-Excellent
Honey	A-Excellent
Hydraulic Oil (Petro)	A-Excellent
Hydraulic Oil (Synthetic)	A-Excellent
Hydrazine	A-Excellent
Hydrobromic Acid 100%	A-Excellent
Hydrobromic Acid 20%	A-Excellent
Hydrochloric Acid 100%	A-Excellent
Hydrochloric Acid 20%	A-Excellent
Hydrochloric Acid 37%	A-Excellent
Hydrocyanic Acid	A-Excellent
Hydrocyanic Acid (Gas 10%)	A-Excellent
Hydrofluoric Acid 100%	B-Good
Hydrofluoric Acid 20%	A-Excellent
Hydrofluoric Acid 50%	B-Good
Hydrofluoric Acid 75%	B-Good
Hydrofluosilicic Acid 100%	A-Excellent
Hydrofluosilicic Acid 20%	A-Excellent
Hydrogen Gas	A-Excellent
Hydrogen Peroxide 10%	A-Excellent

Hydrogen Peroxide 100%	A-Excellent
Hydrogen Peroxide 30%	A-Excellent
Hydrogen Peroxide 50%	A-Excellent
Hydrogen Sulfide (aqua)	D-Severe Effect
Hydrogen Sulfide (dry)	D-Severe Effect
Hydroquinone	B-Good
Hydroxyacetic Acid 70%	A-Excellent
Ink	A-Excellent
Iodine	A-Excellent
Isooctane	A-Excellent
Isopropyl Acetate	D-Severe Effect
Isopropyl Ether	D-Severe Effect
Isotane	A-Excellent
Jet Fuel (JP3, JP4, JP5)	A-Excellent
Kerosene	A-Excellent
Ketones	D-Severe Effect
Lacquer Thinners	D-Severe Effect
Lacquers	D-Severe Effect
Lactic Acid	A-Excellent
Lard	A-Excellent
Latex	A-Excellent
Lead Acetate	D-Severe Effect
Lead Nitrate	A-Excellent
Lead Sulfamate	A-Excellent
Ligroin	A-Excellent
Lime	A-Excellent
Linoleic Acid	B-Good
Lithium Chloride	A-Excellent
Lubricants	A-Excellent
Lye: Ca(OH)2 Calcium Hydroxide	B-Good
Lye: KOH Potassium Hydroxide	B-Good
Lye: NaOH Sodium Hydroxide	B-Good
Magnesium Carbonate	A-Excellent
Magnesium Chloride	A-Excellent
Magnesium Hydroxide	A-Excellent
Magnesium Nitrate	A-Excellent
Magnesium Oxide	C-Fair
Magnesium Sulfate (Epsom Salts)	A-Excellent
Maleic Acid	A-Excellent
Maleic Anhydride	A-Excellent
Malic Acid	A-Excellent
Manganese Sulfate	A-Excellent
Mash	A-Excellent
Mayonnaise	A-Excellent
Melamine	A-Excellent
Mercuric Chloride (dilute)	A-Excellent
Mercuric Cyanide	A-Excellent

Mercurous Nitrate	A-Excellent
Mercury	A-Excellent
Methane	A-Excellent
Methanol (Methyl Alcohol)	C-Fair
Methyl Acetate	D-Severe Effect
Methyl Acetone	D-Severe Effect
Methyl Acrylate	D-Severe Effect
Methyl Alcohol 10%	C-Fair
Methyl Bromide	A-Excellent
Methyl Butyl Ketone	D-Severe Effect
Methyl Cellosolve	D-Severe Effect
Methyl Chloride	A-Excellent
Methyl Dichloride	A-Excellent
Methyl Ethyl Ketone	D-Severe Effect
Methyl Ethyl Ketone Peroxide	D-Severe Effect
Methyl Isobutyl Ketone	D-Severe Effect
Methyl Isopropyl Ketone	D-Severe Effect
Methyl Methacrylate	D-Severe Effect
Methylamine	D-Severe Effect
Methylene Chloride	B-Good
Milk	A-Excellent
Mineral Spirits	A-Excellent
Molasses	A-Excellent
Monochloroacetic acid	C-Fair
Monoethanolamine	D-Severe Effect
Mustard	D-Severe Effect
Naphtha	A-Excellent
Naphthalene	A-Excellent
Natural Gas	A-Excellent
Nickel Chloride	A-Excellent
Nickel Nitrate	A-Excellent
Nickel Sulfate	A-Excellent
Nitric Acid (20%)	A-Excellent
Nitric Acid (50%)	A-Excellent
Nitric Acid (5-10%)	A-Excellent
Nitric Acid (Concentrated)	A-Excellent
Nitrobenzene	B-Good
Nitromethane	D-Severe Effect
Nitrous Acid	B-Good
Nitrous Oxide	B-Good
Oils:Aniline	C-Fair
Oils:Bay	A-Excellent
Oils:Bone	A-Excellent
Oils:Castor	A-Excellent
Oils:Cinnamon	A-Excellent
Oils:Citric	A-Excellent
Oils:Clove	A-Excellent

Oils:Coconut	A-Excellent
Oils:Cod Liver	A-Excellent
Oils:Corn	B-Good
Oils:Cottonseed	A-Excellent
Oils:Creosote	A-Excellent
Oils:Diesel Fuel (20, 30, 40, 50)	A-Excellent
Oils:Fuel (1, 2, 3, 5A, 5B, 6)	B-Good
Oils:Ginger	A-Excellent
Oils:Hydraulic Oil (Petro)	A-Excellent
Oils:Hydraulic Oil (Synthetic)	A-Excellent
Oils:Lemon	A-Excellent
Oils:Linseed	A-Excellent
Oils:Mineral	A-Excellent
Oils:Olive	A-Excellent
Oils:Orange	A-Excellent
Oils:Palm	A-Excellent
Oils:Peanut	A-Excellent
Oils:Peppermint	A-Excellent
Oils:Pine	A-Excellent
Oils:Rapeseed	A-Excellent
Oils:Rosin	A-Excellent
Oils:Sesame Seed	A-Excellent
Oils:Silicone	A-Excellent
Oils:Soybean	A-Excellent
Oils:Sperm (whale)	A-Excellent
Oils:Tanning	A-Excellent
Oils:Transformer	A-Excellent
Oils:Turbine	A-Excellent
Oleic Acid	B-Good
Oleum 100%	A-Excellent
Oleum 25%	A-Excellent
Oxalic Acid (cold)	A-Excellent
Ozone	A-Excellent
Palmitic Acid	A-Excellent
Paraffin	B-Good
Pentane	A-Excellent
Perchloric Acid	A-Excellent
Perchloroethylene	A-Excellent
Petrolatum	A-Excellent
Petroleum	A-Excellent
Phenol (10%)	A-Excellent
Phenol (Carbolic Acid)	A-Excellent
Phosphoric Acid (>40%)	A-Excellent
Phosphoric Acid (crude)	A-Excellent
Phosphoric Acid (S40%)	A-Excellent
Phosphorus Trichloride	A-Excellent
Photographic Developer	A-Excellent

Photographic Solutions	B-Good
Phthalic Acid	A-Excellent
Phthalic Anhydride	A-Excellent
Picric Acid	A-Excellent
Plating Solutions, Antimony Plating 130°F	A-Excellent
Plating Solutions, Arsenic Plating 110°F	A-Excellent
Plating Solutions, Brass Plating: High-Speed Brass Bath 110°F	A-Excellent
Plating Solutions, Brass Plating: Regular Brass Bath 100°F	A-Excellent
Plating Solutions, Bronze Plating: Cu-Cd Bronze Bath R.T.	A-Excellent
Plating Solutions, Bronze Plating: Cu-Sn Bronze Bath 160°F	A-Excellent
Plating Solutions, Bronze Plating: Cu-Zn Bronze Bath 100°F	A-Excellent
Plating Solutions, Cadmium Plating: Cyanide Bath 90°F	A-Excellent
Plating Solutions, Cadmium Plating: Fluoborate Bath 100°F	A-Excellent
Plating Solutions, Chromium Plating: Barrel Chrome Bath 95°F	C-Fair
Plating Solutions, Chromium Plating: Black Chrome Bath 115°F	C-Fair
Plating Solutions, Chromium Plating: Chromic-Sulfuric Bath 130°F	C-Fair
Plating Solutions, Chromium Plating: Fluoride Bath 130°F	C-Fair
Plating Solutions, Chromium Plating: Fluosilicate Bath 95°F	C-Fair
Plating Solutions, Copper Plating (Acid): Copper Fluoborate Bath 120°F	A-Excellent
Plating Solutions, Copper Plating (Acid): Copper Sulfate Bath R.T.	A-Excellent
Plating Solutions, Copper Plating (Cyanide): Copper Strike Bath 120°F	A-Excellent
Plating Solutions, Copper Plating (Cyanide): High-Speed Bath 180°F	A-Excellent
Plating Solutions, Copper Plating (Cyanide): Rochelle Salt Bath 150°F	A-Excellent
Plating Solutions, Copper Plating (Misc): Copper (Electroless)	A-Excellent
Plating Solutions, Copper Plating (Misc): Copper Pyrophosphate	A-Excellent
Plating Solutions, Gold Plating: Acid 75°F	A-Excellent
Plating Solutions, Gold Plating: Cyanide 150°F	A-Excellent
Plating Solutions, Gold Plating: Neutral 75°F	A-Excellent
Plating Solutions, Indium Sulfamate Plating R.T.	A-Excellent
Plating Solutions, Iron Plating: Ferrous Am Sulfate Bath 150°F	A-Excellent
Plating Solutions, Iron Plating: Ferrous Chloride Bath 190°F	A-Excellent
Plating Solutions, Iron Plating: Ferrous Sulfate Bath 150°F	A-Excellent
Plating Solutions, Iron Plating: Fluoborate Bath 145°F	A-Excellent
Plating Solutions, Iron Plating: Sulfamate 140°F	A-Excellent
Plating Solutions, Iron Plating: Sulfate-Chloride Bath 160°F	A-Excellent
Plating Solutions, Lead Fluoborate Plating	A-Excellent
Plating Solutions, Nickel Plating: Electroless 200°F	A-Excellent
Plating Solutions, Nickel Plating: Fluoborate 100-170°F	A-Excellent
Plating Solutions, Nickel Plating: High-Chloride 130-160°F	A-Excellent
Plating Solutions, Nickel Plating: Sulfamate 100-140°F	A-Excellent
Plating Solutions, Nickel Plating: Watts Type 115-160°F	A-Excellent
Plating Solutions, Rhodium Plating 120°F	A-Excellent
Plating Solutions, Silver Plating 80-120°F	A-Excellent
Plating Solutions, Tin-Fluoborate Plating 100°F	A-Excellent
Plating Solutions, Tin-Lead Plating 100°F	A-Excellent
Plating Solutions, Zinc Plating: Acid Chloride 140°F	A-Excellent
Plating Solutions, Zinc Plating: Acid Fluoborate Bath R.T.	A-Excellent

Plating Solutions, Zinc Plating: Acid Sulfate Bath 150°F	A-Excellent
Plating Solutions, Zinc Plating: Alkaline Cyanide Bath R.T.	A-Excellent
Potash (Potassium Carbonate)	A-Excellent
Potassium Bicarbonate	A-Excellent
Potassium Bromide	A-Excellent
Potassium Chlorate	A-Excellent
Potassium Chloride	A-Excellent
Potassium Chromate	A-Excellent
Potassium Cyanide Solutions	A-Excellent
Potassium Dichromate	A-Excellent
Potassium Ferricyanide	A-Excellent
Potassium Ferrocyanide	A-Excellent
Potassium Hydroxide (Caustic Potash)	B-Good
Potassium Iodide	A-Excellent
Potassium Nitrate	A-Excellent
Potassium Permanganate	A-Excellent
Potassium Sulfate	A-Excellent
Potassium Sulfide	A-Excellent
Propane (liquefied)	A-Excellent
Propylene	A-Excellent
Propylene Glycol	A-Excellent
Pyridine	D-Severe Effect
Pyrogallic Acid	A-Excellent
Resorcinal	A-Excellent
Rosins	A-Excellent
Rum	A-Excellent
Rust Inhibitors	A-Excellent
Salad Dressings	A-Excellent
Salicylic Acid	A-Excellent
Salt Brine (NaCl saturated)	A-Excellent
Sea Water	A-Excellent
Shellac (Bleached)	A-Excellent
Shellac (Orange)	A-Excellent
Silicone	A-Excellent
Silver Nitrate	A-Excellent
Soap Solutions	A-Excellent
Soda Ash (see Sodium Carbonate)	A-Excellent
Sodium Acetate	D-Severe Effect
Sodium Aluminate	A-Excellent
Sodium Benzoate	A-Excellent
Sodium Bicarbonate	A-Excellent
Sodium Bisulfate	A-Excellent
Sodium Bisulfite	A-Excellent
Sodium Borate (Borax)	A-Excellent
Sodium Bromide	A-Excellent
Sodium Carbonate	A-Excellent
Sodium Chlorate	A-Excellent

Sodium Chloride	A-Excellent
Sodium Chromate	A-Excellent
Sodium Cyanide	A-Excellent
Sodium Ferrocyanide	A-Excellent
Sodium Fluoride	A-Excellent
Sodium Hydrosulfite	A-Excellent
Sodium Hydroxide (20%)	C-Fair
Sodium Hydroxide (50%)	D-Severe Effect
Sodium Hydroxide (80%)	D-Severe Effect
Sodium Hypochlorite (<20%)	A-Excellent
Sodium Hypochlorite (100%)	A-Excellent
Sodium Metaphosphate	A-Excellent
Sodium Metasilicate	A-Excellent
Sodium Nitrate	A-Excellent
Sodium Perborate	A-Excellent
Sodium Peroxide	A-Excellent
Sodium Polyphosphate	A-Excellent
Sodium Silicate	A-Excellent
Sodium Sulfate	A-Excellent
Sodium Sulfide	A-Excellent
Sodium Sulfite	A-Excellent
Sodium Tetraborate	A-Excellent
Sodium Thiosulfate (hypo)	A-Excellent
Sorghum	A-Excellent
Soy Sauce	A-Excellent
Stannic Chloride	A-Excellent
Stannic Fluoborate	A-Excellent
Stannous Chloride	A-Excellent
Starch	A-Excellent
Stearic Acid	A-Excellent
Stoddard Solvent	A-Excellent
Styrene	B-Good
Sugar (Liquids)	A-Excellent
Sulfate (Liquors)	A-Excellent
Sulfur Chloride	A-Excellent
Sulfur Dioxide	A-Excellent
Sulfur Dioxide (dry)	A-Excellent
Sulfur Trioxide	A-Excellent
Sulfur Trioxide (dry)	A-Excellent
Sulfuric Acid (<10%)	A-Excellent
Sulfuric Acid (10-75%)	A-Excellent
Sulfuric Acid (75-100%)	A-Excellent
Sulfuric Acid (cold concentrated)	B-Good
Sulfuric Acid (hot concentrated)	A-Excellent
Sulfurous Acid	A-Excellent
Tallow	A-Excellent
Tannic Acid	A-Excellent

Tanning Liquors	A-Excellent
Tartaric Acid	A-Excellent
Tetrachloroethane	A-Excellent
Tetrachloroethylene	A-Excellent
Tetrahydrofuran	D-Severe Effect
Tin Salts	A-Excellent
Toluene (Toluol)	C-Fair
Tomato Juice	A-Excellent
Trichloroacetic Acid	C-Fair
Trichloroethane	A-Excellent
Trichloroethylene	A-Excellent
Trichloropropane	A-Excellent
Tricresylphosphate	A-Excellent
Triethylamine	D-Severe Effect
Trisodium Phosphate	A-Excellent
Turpentine	A-Excellent
Urea	A-Excellent
Urine	A-Excellent
Varnish	A-Excellent
Vegetable Juice	A-Excellent
Vinegar	A-Excellent
Vinyl Acetate	A-Excellent
Vinyl Chloride	A-Excellent
Water, Acid, Mine	A-Excellent
Water, Deionized	A-Excellent
Water, Distilled	A-Excellent
Water, Fresh	A-Excellent
Water, Salt	A-Excellent
Weed Killers	A-Excellent
Whey	A-Excellent
Whiskey & Wines	A-Excellent
White Liquor (Pulp Mill)	A-Excellent
White Water (Paper Mill)	A-Excellent
Xylene	B-Good
Zinc Chloride	A-Excellent
Zinc Sulfate	A-Excellent

Enclosure 1

Item 3 - RSI supporting references

(b). RSI 3-3

- Proprietary thermal analysis ANSYS input/output file data disk

DATA DISC PROVIDED WITH SUBMITTED PROPRIETARY BINDER PACKAGE

Enclosure 1
Item 3 - RSI supporting references
(c). RSI 6-1

- Proprietary criticality analysis input/output file data disk

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Technical Information

Teflon® AF

amorphous fluoropolymers

Safety in Handling and Use

Introduction

This technical information provides guidelines for the safe handling and use of *Teflon®* AF amorphous fluoropolymer resins. Temperatures, ventilation, scrap disposal, soldering, and machining are considered.

Pyrolysis Studies

Weight Loss vs. Temperature

Teflon® AF resins are thermally stable up to about 360°C (680°F) in air. Using sensitive analytical techniques, the isothermal rate of weight loss of *Teflon®* AF in air at 360°C (680°F) has been shown to be 0.2 to 0.6%/hr. Compared with other polymers, the weight loss rates for *Teflon®* AF resins are extremely low and similar to rates for *Teflon®* FEP.

Decomposition Products

When *Teflon®* AF resins are decomposed in air at temperatures from 360 to 450°C (680 to 842°F), products observed are HF from reaction of COF_2 with moist air, COF_2, CO, and hexafluoroacetone (HFA). The amount of HFA evolved upon complete decomposition at 500°C (932°F) is up to 100–200 mg/g of sample.

The OSHA permissible exposure limit for HF is 3 ppm, and for HFA is 0.1 ppm. In animal tests, HFA has been shown to be a potent reproductive and developmental toxin. To protect against reproductive or developmental hazards from HFA fumes, DuPont recommends an exposure limit of 0.1 ppm for men and women not of childbearing capability, and 0.005 ppm for women of childbearing capability. A skin notation, denoting that measures should be taken to protect against significant skin absorption, applies for HFA hydrates.

Handling Practices

Teflon® AF resins contain parts per million of residual HFA. Because HFA hydrates are readily absorbed through the skin, it is necessary to avoid skin contact with the resin during processing. DuPont recommends the use of protective gloves if handling of the resin is required during manufacturing operations.

Some residual gases (including HF, COF_2, CO, and HFA), which may be harmful, diffuse from *Teflon®* AF resins even at room temperature. Therefore, to avoid exposure, all resin containers should be opened and used only in well-ventilated areas using local exhaust ventilation (LEV).

In addition, it is recommended that exhaust hoods be installed to remove *all* of the off-gases released from hot polymers in work areas. For this purpose, a number of hood designs are shown in **Figure 1**. These designs present several alternatives to allow adequate exhaust volumes for effective capture and removal of all of the off-gases.

The types of situations normally encountered and the capture velocities needed to remove all the gases from the local vicinity of the hot polymer are summarized in **Table 1**.

The type of work situation is selected from **Table 1**, and the centerline velocity required to capture all of the gases is then used to calculate the volumetric rate of air flow (in m^3s/cfm) required for the hood selected from **Figure 1**. For example, in the extrusion coating of wire, a capture velocity of 1 m/s (200 fpm) may be needed. A hood of the plain-opening design with an area of its face of 0.05 m^2 (0.5 sq ft) is placed 0.15 m (0.5 ft) above the discharge face of the extruder. To remove all the gases generated at the face of this hood, an air volume of 600 cfm (0.28 m^3/s) is needed, as calculated below (note that all dimensions must be expressed in meters or feet):

$$Q = V\,(10X^2 + A)$$
$$Q = 200\,(10\,[0.5]^2 + 0.5)$$
$$Q = 600 \text{ cfm}$$
$$Q = V\,(10X^2 + A)$$
$$Q = 1\,(10\,[0.15]^2 + 0.05)$$
$$Q = 0.28 \text{ m}^3/\text{s}$$

Teflon® is a registered trademark of DuPont.

The importance of locating the hood opening close to the hot polymer is indicated by the fact that the "X" dimension is raised to the second power in the above equation. Thus, if this dimension were doubled in the above example, the volumetric rate of air flow required would increase to $200\ (10 \times 1^2 + 0.5) = 2100$ cfm/1.0 m^3/s, a rise of 250%.

Machining

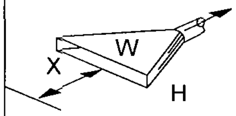
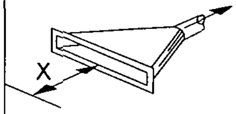
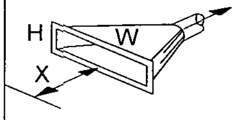
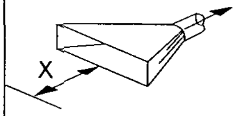
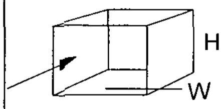
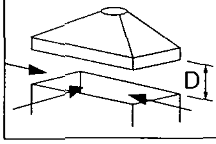
In grinding, sawing, and machining of *Teflon*® AF, measures should be taken to ensure that temperatures are maintained below 360°C (680°F). Generally, coolants are recommended in machining fluoropolymer resins to improve production rates and quality, and they can serve to control any tendency toward overheating.

Respirable Dust

In any manufacturing or handling operation where dust from *Teflon*® AF may be created. the concentration of airborne dust should not be permitted to exceed the OSHA permissible exposure limits of 5 mg/m^3 respirable dust or 15 mg/m^3 total dust.

It is strongly recommended that tobacco not be used or carried in open packs around machining operations or where resin dust may be encountered, because smoking tobacco contaminated with fluoropolymer dust will result in inhalation of toxic thermal decomposition products.

Figure 1. Hood Design Data

Hood Types	Description	Aspect Ratio, H/W	Air Rate**
	Slot	0.2 or less	Q = 3.7 WVX
	Flanged slot*	0.2 or less	Q = 2.8 WVX
	Plain opening	0.2 or greater and round	Q = V $(10X^2 + A)$
	Flanged opening*	0.2 or greater and round	Q = 0.75V $(10X^2 + A)$
	Booth	To suit work	Q = VA = VWH
	Canopy	To suit work	Q = 1.4 PDV

*Wherever possible, flanges should be provided to eliminate air flow from ineffective zones where no contaminant exists. Increasing the hood effectiveness in this manner will usually reduce air requirements by 25%. For most applications the flange width can be equal to the hood diameter or side but need not exceed 15 cm (6 in).

**Nomenclature

V = Centerline velocity at X distance from face of hood, m/s (fpm) (use recommended capture velocities from **Table 1**)
X = Distance from source to face of hood, m (ft)
Q = Air volume, m^3/s (cfm)
A = Area at face of hood, m^2 (sq ft)
P = Perimeter of work, lin m (lin ft)
D = Height above the work, m (ft)
H = Height of hood, m (ft)
W = Width of hood, m (ft)

Table 1
Capture Velocities Recommended in Various Work Situations

Dispersion of Contaminants into Air	Examples	Capture Velocity, m/s (fpm)
Released with practically no velocity into quiet air.	Drying of fluoropolymer resins—granular, powder, cubes; evaporation of solvents, water, etc.	(0.25–0.50) 50–100
Released at low velocity into moderately still air.	Spray coating with solutions. Normal blending of fluoropolymer cubes or powders. Molding of fluoropolymer resins.	(0.50–1.0) 100–200
Active generation into zone of rapid air motion.	Melt extrusion of fluoropolymer resins. Injection and transfer molding of resins.	(1.0–2.5) 200–500
Released at high initial velocity into zone of very rapid air motion.	Grinding and machining of parts from fluoropolymer resins. High-speed mixing of fluoropolymer powders in turbulent mode.	(2.5–10.0) 500–2,000

In each category above, a range of capture velocities is shown.
The proper choice of values depends on several factors:

Lower End of Range	Upper End of Range
1. Room air current minimal or favorable to capture	1. Disturbing room air currents
2. Contaminants of low toxicity	2. Contaminants of high toxicity
3. Intermittent, low production	3. High production, heavy use
4. Large hood—large air mass in motion	4. Small hood—local control only

Soldering and Melt Stripping

The combined effects of temperature, quantity of resin, exposure time, and ventilation conditions during soldering and melt stripping are unlikely to produce conditions of toxicological significance. Any special practices that may be warranted will follow the rules applicable to any soldering work. For example, prolonged soldering in confined spaces where natural air circulation is restricted will require mechanical ventilation. The same is true for shop areas where a number of workers are engaged in soldering or melt stripping operations. Normal ventilation provided for worker comfort usually provides adequate safety for these operations. As an added measure during melt stripping and soldering, many shops use an exhaust duct at each work station.

Scrap Disposal

Disposal of scrap *Teflon*® AF presents no special problem to the user. It is best to dispose of such scrap in a landfill dump without burning.

Small amounts of scrap, up to approximately 5 kg (10 lb) at a time, are often incinerated along with general plant refuse. The incinerator should have sufficient draft to exhaust all combustion products to the stack. Normal care should be taken to avoid breathing smoke and fumes from any fire. In addition, because many polymers produce acids in their combustion products (in the presence of moisture, decomposition products of fluoropolymers contain HF), the stack should be high enough to dilute the acid content of the exhaust gases to an acceptable level. HF causes strong eye and nose irritation before approaching systemically toxic levels. It is also capable of etching glass. In addition, vegetation is particularly sensitive to HF. Where desirable vegetation is present, do not burn scrap fluoropolymers in an open dump during periods of heavy humidity, fog, or smog.

In the reclamation of metals by melting of scrap, it is advisable first to remove any nonmetallic components in order to avoid generating more organic vapors than necessary. The furnace should have sufficient draft to exhaust all gases to the stack.

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Teflon offgas studies

MAY 15, 2003

Over the past five decades scientists from DuPont, government, and academia have published studies documenting temperatures at which non-stick cookware coatings begin to break apart, offgasing chemicals and particulate matter into the air. Dealing with multiple cases of polymer fume fever in their workers, DuPont scientists conducted a series of studies beginning in the 1950s to identify the toxic components from heated Teflon, killing birds and rats in efforts to understand the potency of the gases and particles.

Teflon Decomposition Products:

Studies show that thermal degradation of Teflon leads to the slow breakdown of the fluorinated polymer and the generation of a litany of toxic fumes including TFE (tetrafluoroethylene), HFP (hexafluoropropene), OFCB (octafluorocyclobutane), PFIB (perfluoroisobutane), carbonyl fluoride, CF_4 (carbon tetrafluoride), TFA (trifluoroacetic acid), trifluoroacetic acid fluoride, perfluorobutane, SiF_4 (silicon tetrafluoride), HF (hydrofluoric acid), and particulate matter. At least four of these gases are extremely toxic - PFIB, which is a chemical warfare agent 10 times more toxic than phosgene ($COCl_2$, a chemical warfare agent used during World Wars I and II), carbonyl fluoride (COF_2 which is the fluorine analog of phosgene), MFA (monofluoroacetic acid) which can kill people at low doses, and HF, a highly corrosive gas.

Many of the thermal degradation products are unmatched in their environmental persistence. Besides fire and heating, which are not considered normal methods of environmental degradation, some of these compounds have no known degradation methods, including four gaseous chemicals (TFA, PFOA, CF_4, PFB) and some components of the particulate matter that are highly persistent. TFA and the other PFOA-like perfluorinated acids that have been detected in Teflon degradation studies have "no known significant loss mechanism" [1]. In addition, the perfluorinated alkene HFP, which makes up the bulk of the degradation products at temperatures above 680 F (360 C), will react with OH radicals in the troposphere to produce TFA with 100% conversion [2].

The lowest temperature at which nonstick coatings have been reported to kill birds in a peer-reviewed study is 396 F (202 C) [3]. In May 1998, poultry researchers at the University of Missouri recorded 52 percent mortality in 2400 chicks within three days of the birds being placed into floor pens with new PTFE-coated heat lamp bulbs. After ruling out bacterial infections like E. Coli and Salmonella, or toxic gases such as sulfur dioxide, carbon monoxide and carbon dioxide, the scientists finally linked the chick deaths to offgas products from the PTFE-coated bulbs. All of the chicks examined after death had lung lesions and moderate to severe pulmonary edema consistent with "PTFE toxicosis."

The researchers also learned from a private communication with Dr. Bedros Nersessian that a duck research facility that used the same PTFE-coated heat lamps had 23.3 percent death in ducklings, over 400 ducklings in all, within five days [3]. In 1997, two English veterinarians reported a case in which eight raptor deaths over three months were attributed to PTFE coated heat lamps. This incident was described in a letter on PTFE toxicity in birds published in the journal Veterinary Record [4]. In addition, an inadvertent poisoning of pet birds has been reported when a Teflon-coated surface was heated to 325 F (163 C) | **View Bird Death Diaries**

These reports and personal accounts indicate that Teflon offgases toxic substances at temperatures as low as 396 F and 325 F. In 1991, a report by a collaborative team of DuPont and Louisiana State University scientists also addressed this issue. These scientists generated low molecular weight PTFE by heating Teflon to high temperatures and allowing the fumes to age for a few minutes; aging allowed the chemicals in the fumes to react to form small Teflon molecules. The scientists found that when this low molecular weight PTFE was reheated to 464 F two out of three exposed rats died. Evidence indicated that particulate matter was responsible for the rats' death, and this particulate matter was composed of small molecules of Teflon [5].

Seidel and coworkers explain that "fumes generated at temperatures below 572 F (300 C) are formed exclusively by sublimation of a low MW (molecular weight) fraction already present in the polymer"[5]. From the Seidel study we can conclude that at low temperatures PTFE offgases particulate matter which is composed of small molecules of PTFE. We can also conclude that this particulate matter, which has been reported to cause bird deaths at temperatures below 500 F (260 C), is the result of the presence of low molecular weight PTFE

This low molecular weight PTFE may be present in Teflon at the time of Teflon's manufacture, or the PTFE may be created when a pan is heated repeatedly and the coating degrades as PTFE bonds break. PTFE particles have been measured in offgas products at temperatures as high as 1067 F (575 C).

According to Waritz's 1975 paper, particulate matter is emitted from Teflon pans between 554 F and 1067 F (290 and 575 C)[6]. These particles have been linked to bird deaths that can occur when an empty pan is heated on a burner. At these temperature the Teflon molecule breaks apart into smaller Teflon particles. When this occurs the carbon-carbon bonds of Teflon break, generating free radicals; these free radicals can then form alkenes, or they can react with oxygen to form carboxylic acids (forming PFOA, a chemical for which EPA is considering regulatory action, and PFOA-like compounds). The resulting particulate matter is thus a mixture of perfluorinated alkanes, perfluorinated alkenes, and perfluorinated acids [3, 7]

Many studies have established the toxicity of particulate matter generated at temperatures above 554 F (290 C) A study conducted by Zapp et al. in 1955 first indicated that particulate matter was implicated in the toxicity of PTFE [8]. In 1959, Clayton et al found that PTFE resins will generate toxic products when heated in air Clayton showed that the particulate matter is toxic when he demonstrated that the toxicity of the offgas products is removed when the PTFE offgas products are filtered to remove the particulate matter before animal exposure [9].

In 1968, DuPont scientists Waritz and Kwon showed that rats exposed to a 20 gram sample of PTFE heated to 842 F (450 C) produced death within four hours. The authors note that "exposures lasted four hours unless all rats exposed succumbed earlier," [10] but they failed to report the time to death among the rats It was found that when the particulate matter was filtered from the offgas products before the rats were exposed, the mortality was reduced to zero; this provides evidence that the particulate matter is required for toxicity at 842 F. Based on the concentrations of particulate matter that caused rat death, Waritz and Kwon calculate that particulate matter is lethal at concentrations of only 1.4 parts per million (ppm) [10].

In a 1975 study by Waritz, Teflon breakdown products generated at lower temperatures were determined to cause death Within four hours of exposure to a Teflon-coated pan heated to 536 F (280 C) parakeets died, and quail were killed when the pan was heated to 626 F or 330 C. These temperatures are easily accessible on a stovetop Rats were killed within four hours when a Teflon pan was heated to between 797 F and 842 F (425 to 450 C). Once again, the DuPont scientist failed to report the time to death for the animals [6].

Many gases are also evolved when Teflon is heated. Heated to temperatures between 680 and 1112 F (360 to 600 C), Teflon generates TFE [1, 11]. This chemical is one of 174 chemicals that the National Toxicology Program considers to be reasonably anticipated human carcinogens [12]. Teflon heated to between 680 and 1202 F (360 and 650 C) will also generate HFP [1, 11]. Carbonyl fluoride, COF2, a toxic gas and the fluorinated cousin of the chemical warfare agent phosgene, is emitted from Teflon that is heated between 824 F and 1292 F (440 and 700 C) [6, 11] PFIB, perfluoroisobutene, a chemical warfare agent that is ten times more toxic than phosgene, is detected when Teflon is heated in air between 887 F and 1004 F (475 and 540 C) [6]. Above 1202 F (650 C), carbon tetrafluoroide and carbon dioxide are the major products generated during the decomposition [7]

Other chemicals that have been detected in the offgas products of heated Teflon are trifluoroacetetic acid (TFA), difluoroacetic acid (DFA), and monofluoroacetic acid (MFA, also known as compound 1080, a pesticide and historical chemical warfare agent which has an LD50 of 0.7 – 2.1 mg/kg in men [13]), and various other perfluorinated acids with the general formula $CF_3(CF_2)_nCO_2H$; these acids were detected by University of Toronto scientists Ellis and Mabury (and coworkers) in a 2001 study in which Teflon was heated to 680 F (360 C) for 2 hours [1] Finally, in the presence of glass (SiO_2), SiF_4 has been detected in the offgas products when teflon is heated to temperatures of 878 F (470 C)and higher [7, 11]; SiF_4 is also a toxic gas and it has been reported that the presence of SiF4 enhances the toxicity of the other toxic Teflon offgas products [14].

In a recent PTFE rat toxicity study, Dr Carl Johnston et al. found that neither the ultrafine particles or the gases produced by PTFE are toxic by themselves, but the two together are extremely toxic together [15]. The authors suggest the particles are acting as carriers for absorbed gas particles, allowing the gas particles to travel to the lower respiratory tract and cause severe damage. Alternatively, the particles could be generating toxic reactive groups on their surfaces. Also, the size of the particles matters. The most toxic particles are called ultrafine and are 16 nanometers in diameter. If the particles are able to coagulate and form larger particles, greater than 100 nm, they are not as acutely toxic to rats.

In one case of human polymer fume fever in the literature, the author reports a case in which a person developed polymer fume fever about one hour after a non-stick pan overheated. Five cockatiels in the house died within 30 minutes [16]. In another case, a healthy 26-year-old woman went to the hospital complaining of difficult breathing, chest tightness and cough after being exposed to toxic fumes coming from a defective microwave oven part: a melted and scorched Teflon block used as an axle for a rotating platform in the oven. At the hospital, doctors noted that her heart was racing, and she had high blood pressure, increased white blood cell count (leukocytosis) and was breathing heavily. An X-ray showed she had "diffuse pulmonary infiltrate." Her lung function was still abnormal a month later This woman's two pet parakeets died within minutes of being exposed to the Teflon fumes [17].

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Enclosure 2

List of Changes

NAC-LWT SAR, Revision LWT-13B

HEUNL Amendment – RSI Responses

List of Changes, NAC-LWT SAR, Revision LWT-13B

Note: The List of Effective Pages and the Chapter Tables of Contents, including the List of Figures, the List of Tables, and the List of Drawings, were revised as needed to incorporate the following changes.

Chapter 1

- Page 1.1-2, added "with a similar acid solution" to last sentence on page.
- Page 1.2-6, added "with a similar acid solution" to Item 21, last sentence on page.
- Page 1.2-18, Section 1.2.3.12, added sentence to middle of 1st paragraph, and added new paragraph (2nd in section) to subsection 1.2.3.12, "HEUNL Containers."
- Page 1.2-53, modified last value in Table 1.2.3-14, "HEUNL Characteristics" to state "7.2 g ^{235}U/L."

Chapter 2

- Page 2.2.1-2, modified numbers for HEUNL in bottom two rows of Table 2.2.1-1.
- Page 2.2.1-4, modified numbers for HEUNL in 3rd and 4th rows of Table 2.2.1-2.
- Page 2.6.12-1, modified subsection 2.6.12.1, "Discussion"; added reference to HEUNL container section 2.6.12.13 and added sentence saying HEUNL payload is bounded by design basis payload.
- Page 2.6.12-95, and 2.6.12-97 thru 2.6.12-104, numerous changes throughout subsection 2.6.12.13, "HEUNL Container."
- Pages 2.7.7-75 thru 2.7.7-77, made numerous changes throughout subsection 2.7.7.15.2, and added the "Thermal Expansion" paragraph at the end of the subsection.

Chapter 3

- Page 3.4-38, modified last paragraph on page.
- Pages 3.4-56 thru 3.4-57, added new subsection 3.4.4.9, "Maximum Internal Pressure for HEUNL Contents."
- Page 3.5-14, modified 2nd paragraph of subsection 3.5.3.16, "Evaluation of HEUNL."
- Page 3.5-15, text flow.
- Page 3.5-18, due to text flow, start of Section 3.5.5 moved to the bottom of page 3.5-19, following new subsection 3.5.4.8.
- Page 3.5-19, added new subsection 3.5.4.8, "Maximum Internal Pressure for HEUNL Contents."
- Page 3.5-20, text flow.

List of Changes, NAC-LWT SAR, Revision LWT-13B (cont'd)

Chapter 4

- Page 4.1-1, added the last sentence to the first paragraph in Section 4.1, "Containment Boundary."
- Page 4.1-3, modified last sentence in last paragraph of Section 4.1.3, "Closure."
- Page 4.1-4, added new Figure 4.1-1, "Cask Containment Boundary."
- Page 4.2-2, modified last paragraph of Section 4.2.2, "Pressurization of Containment Vessel."
- Page 4.3-4, modified subsection 4.3.2.3, "HEUNL Containment."
- Pages 4.5-42 thru 4.5-43, added new Section 4.5.6, "Pressure and Flammability Evaluation of HEUNL Container."

Chapter 5

- No changes

Chapter 6

- Page 6.4.3-11, moved "Set H" from page 6.4.3-12.
- Page 6.4.3-12, added 2nd paragraph to "Set I."
- Page 6.4.3-27, added Note "(6)" callout to Table 6.4.3-21, "Baseline MTR Bounding Configurations," in row "Active fuel height", column "Generic;" and added footnote text in "Notes" below the table.
- Pages 6.7.2-3 thru 6.7.2-23, modified Section 6.7.2, "HEUNL" throughout, adding information for the uranyl nitrate – water mixture content; modified titles for Table 6.7.2-9 and Table 6.7.2-10, as follows:
    - Page 6.7.2-3, Section 6.7.2.3, "Criticality Calculations" – modified 2nd sentence of 3rd paragraph; added last sentence to 3rd paragraph; modified 4th paragraph.
    - [redacted]
    - Page 6.7.2-7, modified bullets.
    - Page 6.7.2-8, added new subsection, "Water Reflector and Canister Dimensions".
    - Page 6.7.2-9 thru 6.7.2-18, text flow.

List of Changes, NAC-LWT SAR, Revision LWT-13B (cont'd)

Chapter 6 (continued)

  - [redacted]
  - Pages 6.7.2-21 through 6.7.2-22, modified by text flow.
  - Page 6.7.2-23, added Table 6.7.2-19, "HEUNL Reactivity Comparisons for Design Modification and Reflector Dimension Change."

Chapter 6 Appendices

- No changes.

Chapter 7

- Page 7.1-1, modified the second to last paragraph.
- Page 7.1-2, text flow.
- Pages 7.1-58 thru 7.1-60, Section 7.1.13, "Procedure for Loading HEUNL Into the NAC-LWT Cask," modified last sentence of paragraph prior to numbered items; added last sentence to Item 8; added Items 9, 12, and 13; added sentence to the end of Item 16; existing items renumbered due to addition of items 9, 12, and 13.

Chapter 8

- Page 8.1-9, modified first two paragraphs of subsection 8.1.4.4, "HEUNL Container."
- Page 8.2-2, modified the 2nd full paragraph.
- Page 8.2-3, text flow changes.
- Page 8.2-5, modified the last row, "HEUNL Container," to Table 8.2-1.

Chapter 9

- No changes

Enclosure 3

List of Drawing Changes

NAC-LWT SAR, Revision LWT-13B

HEUNL Amendment

List of Drawing Changes, NAC-LWT SAR, Revision LWT-13B

Drawing 315-40-180, Revision 1P

1. [redacted]
2.
3.

Drawing 315-40-181, Revision 1P

1. [redacted]
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.

Drawing 315-40-182, Revision 1P

1. [redacted]
2.

List of Drawing Changes, NAC-LWT SAR, Revision LWT-13B (cont.)

Drawing 315-40-182, Revision 1P (cont.)

3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.
19.

[redacted]

Drawing 315-40-183, Revision 1P

1.
2.

[redacted]

Enclosure 4

Supporting Calculations

No. 9225 for NAC-LWT Cask

NAC-LWT SAR, Revision LWT-13B

HEUNL Amendment

PROPRIETARY INFORMATION REMOVED

Calculation 65008500-2010

WITHHELD IN ITS ENTIRETY PER 10 CFR 2.390

Enclosure 5

Proposed Changes for Revision 58 of Certificate of Compliance

No. 9225 for NAC-LWT Cask

NAC-LWT SAR, Revision LWT-13B

HEUNL Amendment

Drawings (new)

CoC Page 4 of 33:

LWT 315-40-180, Rev. 1P & 0NP	LWT Transport Cask Assembly, HEUNL Contents
LWT 315-40-181, Rev. 1P & 0NP	Container Assembly, HEUNL
LWT 315-40-182, Rev. 1P & 0NP	Container Spacer, HEUNL
LWT 315-40-183, Rev. 1P & 0NP	Container Guide, HEUNL

CoC Sections (new)

CoC Page 20 of 33:

5.(b)(1) Type and form of material (continued)

(xx) HEUNL as specified below:

Parameter	Liquid HEU
Maximum HEUNL payload per Container	64.3 L (17.0 gal)
Maximum Cask Heat Load	12.88 W
Maximum Per Container Heat Load	3.22 W
Maximum HEUNL Heat Load	0.05 W/L
Maximum Curie Content (gamma emitters)	9.0 Ci/L
Maximum ^{235}U content	7.2 gU/L

CoC Page 29 of 33:

5.(b)(2) Maximum quantity of material per package (continued)

(xxi) For the HEUNL described in Item 5.(b)(1)(xx):

Up to 64.3 L (17.0 gal) of HEUNL may be loaded per container. A total of 4 containers per cask shall be loaded. Each container shall be at the fill capacity or shall be empty in accordance with NAC Drawing Nos. 315-40-181, 315-40-182 and 315-40-183. Dilution with a similar acid solution to achieve fill capacity is permitted. Cask configuration to be in accordance with NAC Drawing No. 315-40-180.

CoC Sections (revised)

CoC Page 8 of 33:

5.(b)(1) Type and form of material (continued)

(iv) (b) Generic MTR Fuel Content Description

Parameter	Limiting Values[2, 3]					
Enrichment, wt. % ^{235}U	≤94					
Number of fuel plates	≤23	≤19	≤23[1]	≤17	≤19	≤23
^{235}U content per plate	≤18	≤20	≤20[1]	≤21	≤21	≤16.5
Plate thickness (cm)	≥0.115	≥0.115	≥0.123[1]	≥0.115	≥.200	≥0.115
Clad Thickness (cm)	≥0.02					
Active fuel width (cm)	≤6.6	≤6.6	≤6.6	≤6.6	≤6.6	≤7.3
Active fuel height (cm)	≥56[3]					
^{235}U content per element (g)	≤380[2]					

Notes:

1. HEU (>90 wt% ^{235}U enriched) MTR fuel having 23 plates with up to 20 g of ^{235}U per plate, with a minimum plate thickness of 0.123 cm, must have at least 2.0 cm of non-fuel material at the ends of each element. This fuel may also be loaded up to 460 g ^{235}U per element.

2. At enrichments ≤25 wt% ^{235}U, MTR fuel elements with extended fuel characteristics may be loaded with the specifications defined in 5.(b)(1)(iv)(c).

3. Reduced active fuel height is permissible for loading provided that the ^{235}U content per plate and ^{235}U content per assembly is proportionally reduced (e.g. a ≤ 7.13 cm active fuel height element is authorized for loading at a minimum of 42 cm active fuel height provided the maximum ^{235}U content per plate is ≤ 12.375 g, 16.5 × 42/56 and ^{235}U content per assembly is ≤ 285 g, 380 × 42/56).

CoC Page 31 of 33:

5(c) Criticality Safety Index (CSI)

For HEUNL described in 5.(b)(1)(xx) and limited in 5.(b)(2)(xxi)	0.0

19. Revision 55, 57 and 58 of this certificate may be used until December TBD, 2013, February TBD, 2014 and December TBD, 2014, respectively.

REFERENCES

NAC International, Inc., application dated June 18, 2010.

NAC International, Inc., supplements dated February 3, March 2, May 24, October 26, December 5 and December 28, 2012; January 24, February 14, and March TBD, 2013.

NRC FORM 618
(8-2000)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1 a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE		PAGES
9225	59	71-9225	USA/9225/B(U)F-96	1	OF	33

2. PREAMBLE

a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, APackaging and Transportation of Radioactive Material.@

b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION

a. ISSUED TO *(Name and Address)*

NAC International, Inc.
3930 East Jones Bridge Road
Norcross, GA 30092

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

NAC International, Inc., application
dated June 18, 2010.

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No.: NAC-LWT

(2) Description

The LWT is a steel-encased, lead shielded shipping cask. The cask is designed to transport various radioactive contents as listed in 5.(b)(1). The overall dimensions of the package, with impact limiters, are 232 inches long by 65 inches in diameter. The cask body is approximately 200 inches in length and 44 inches in diameter. The cask cavity is 178 inches long and 13.4 inches in diameter. The volume of the cavity is approximately 14.5 cubic feet.

The cask body consists of a 0.75-inch-thick stainless steel inner shell, a 5.75-inch-thick lead gamma shield, a 1.2-inch-thick stainless steel outer shell, and a neutron shield tank. The inner and outer shells are welded to a 4-inch-thick stainless steel bottom end forging. The cask bottom consists of a 3-inch-thick, 20.75-inch-diameter lead disk enclosed by a 3.5-inch-thick stainless steel plate and bottom end forging. The cask lid is 11.3-inch-thick stainless steel stepped design, secured to a 14.25-inch-thick ring forging with twelve 1-inch diameter bolts. The cask seal is a metallic O-ring. A second teflon O-ring and a test port are provided to leak test the seal. Other penetrations in the cask cavity include the fill and drain ports, which are sealed with port covers and O-rings.

The neutron shield tank consists of a 0.24-inch-thick stainless steel shell with 0.50-inch-thick end plates. The neutron shield region is 164 inches long and 5 inches thick. The neutron shield tank contains an ethylene glycol/water solution that is 1% boron by weight.

The cask is equipped with aluminum honeycomb impact limiters. The top impact limiter has an outside diameter of 65.25 inches and a maximum thickness of 27.8 inches. The bottom impact limiter has an outside diameter of 60.25 inches and maximum thickness of 28.3 inches. Both impact limiters extend 12 inches along the side of the cask body.

5.(a)(2) Description (continued)

The maximum weight of the package is 52,000 pounds and the maximum weight of the contents and basket is 4,000 pounds.

(3) Drawings

(i) The packaging is constructed in accordance with the following Nuclear Assurance Corporation Drawings:

LWT 315-40-01, Rev. 7	Cask Assembly
LWT 315-40-02, Rev. 24 (Sheets 1-2)	Body Assembly
LWT 315-40-03, Rev. 22 (Sheets 1-7)*	Transport Cask Body
LWT 315-40-04, Rev. 12	Cask Lid Assembly
LWT 315-40-05, Rev. 10	Upper Impact Limiter
LWT 315-40-06, Rev. 10	Lower Impact Limiter
LWT 315-40-08, Rev. 18 (Sheets 1-5)	Cask Parts Detail

* Packaging Unit Nos. 1, 2, 3, 4, and 5 are constructed in accordance with Drawing No. LWT 315-40-03, Rev. 6 (Sheets 1-6).

(ii) The fuel assembly baskets are constructed in accordance with the following Nuclear Assurance Corporation and NAC International Drawings:

LWT 315-40-09, Rev. 2	PWR Basket Spacer
LWT 315-40-10, Rev. 8 (Sheets 1-2)	PWR Basket
LWT 315-40-11, Rev. [illegible]	BWR Basket Assembly
LWT 315-40-12, Rev. 3	Metal Fuel Basket Assembly
LWT 315-40-045, Rev. 6	42 MTR Element Base Module
LWT 315-40-046, Rev. 6	42 MTR Element Intermediate Module
LWT 315-40-047, Rev. 6	42 MTR Element Top Module
LWT 315-40-048, Rev. 3	42 MTR Element Cask Assembly
LWT 315-40-049, Rev. 6	28 MTR Element Base Module
LWT 315-40-050, Rev. 6	28 MTR Element Intermediate Module
LWT 315-40-051, Rev. 6	28 MTR Element Top Module
LWT 315-40-052, Rev. 3	28 MTR Element Cask Assembly
LWT 315-40-070, Rev. 6	7 Cell Basket TRIGA Base Module
LWT 315-40-071, Rev. 6	7 Cell Basket TRIGA Intermediate Module
LWT 315-40-072, Rev. 6	7 Cell Basket TRIGA Top Module
LWT 315-40-079, Rev. 6	Transport Cask Assembly, 120 TRIGA Fuel Elements or 480 Cluster Rods
LWT 315-40-080, Rev. 4	7 Cell Poison Basket TRIGA Base Module
LWT 315-40-081, Rev. 4	7 Cell Poison Basket TRIGA Intermediate Module
LWT 315-40-082, Rev. 4	7 Cell Poison Basket TRIGA Top Module
LWT 315-40-083, Rev. 0	Spacer, LWT Cask Assembly TRIGA Fuel
LWT 315-40-084, Rev. 4	LWT Transport Cask Assy, 140 TRIGA Elements

5.(a)(3)(ii) Drawings (continued)

LWT 315-40-085, Rev. 1	Axial Fuel and Cell Block Spacers, MTR, and TRIGA Fuel Baskets
LWT 315-40-090, Rev. 4	35 MTR Element Base Module
LWT 315-40-091, Rev. 4	35 MTR Element Intermediate Module
LWT 315-40-092, Rev. 4	35 MTR Element Top Module
LWT 315-40-094, Rev. 4	35 MTR Element Cask Assembly
LWT 315-40-096, Rev. 3	Fuel Cluster Rod Insert, TRIGA Fuel
LWT 315-40-098, Rev. 6 (Sheets 1-3)	PWR/BWR Rod Transport Canister Assembly
LWT 315-40-099, Rev. 3 (Sheets 1-3)	Can Weldment, PWR/BWR Transport Canister
LWT 315-40-100, Rev. 4 (Sheets 1-5)	Lids, PWR/BWR Rod Transport Canister
LWT 315-40-101, Rev. 0	4 x 4 Insert, PWR/BWR Transport Canister
LWT 315-40-102, Rev. 2	5 x 5 Insert, PWR/BWR Transport Canister
LWT 315-40-103, Rev. 0	Pin Spacer, PWR/BWR Transport Canister
LWT 315-40-104, Rev. 6 (Sheets 1-3)	LWT Cask Assembly, PWR/BWR Rod Transport Canister
LWT 315-40-105, Rev. 3 (Sheets 1-2)	PWR Insert, PWR/BWR Transport Canister
LWT 315-40-106, Rev. 2 (Sheets 1-3)	MTR Plate Canister, LWT Cask
LWT 315-40-108, Rev. 1 (Sheets 1-3)	7 Cell Basket, Top Module, DIDO Fuel
LWT 315-40-109, Rev. 1 (Sheets 1-3)	7 Cell Basket, Intermediate Module, DIDO Fuel
LWT 315-40-110, Rev. 1 (Sheets 1-3)	7 Cell Basket, Base Module, DIDO Fuel
LWT 315-40-111, Rev. 2	LWT Transport Cask Assy DIDO Fuel
LWT 315-40-113, Rev. 0	Spacer, Top Module DIDO Fuel
LWT 315-40-120, Rev. 2 (Sheets 1-3)	Top Module, General Atomics IFM, LWT Cask
LWT 315-40-123, Rev. 1 (Sheets 1-2)	Spacer, General Atomics IFM, LWT Cask
LWT 315-40-124, Rev. 1	Transport Cask Assembly, General Atomics IFM, LWT Cask
LWT 315-40-125, Rev. 3 (Sheets 1-3)	Transport Cask Assembly, Framatome/EPRI, LWT Cask
LWT 315-40-126, Rev. 2 (Sheets 1-2)	Weldment, Framatome/EPRI, LWT Cask
LWT 315-40-127, Rev. 2 (Sheets 1-2)	Spacer Assembly, TPBAR Shipment
LWT 315-40-129, Rev. 2	Canister Body Assembly, Failed Fuel Can, PULSTAR
LWT 315-40-130, Rev. 2	Assembly, Failed Fuel Can, PULSTAR
LWT 315-40-133, Rev. 2 (Sheets 1-2)	Transport Cask Assembly, PULSTAR Shipment, LWT Cask
LWT 315-40-134, Rev. 2	Body Weldment, Screened Fuel Can, PULSTAR Fuel
LWT 315-40-135, Rev. 1	Assembly, Screened Fuel Can, PULSTAR Fuel
LWT 315-40-139, Rev. 1	Transport Cask Assembly, ANSTO Fuel
LWT 315-40-140, Rev. 1 (Sheets 1-2)	Weldment, 7 Cell Basket, Top Module, ANSTO Fuel

5.(a)(3)(ii) Drawings (continued)

LWT 315-40-141, Rev. 1 (Sheets 1-2)	Weldment, 7 Cell Basket, Intermediate Module, ANSTO Fuel
LWT 315-40-142, Rev. 1 (Sheets 1-2)	Weldment, 7 Cell Basket, Base Module, ANSTO Fuel
LWT 315-40-145, Rev. 0 (Sheets 1-2)	Irradiated Hardware, Lid Spacer, LWT Cask
LWT 315-40-148, Rev. 0	LWT Transport Cask Assembly, ANSTO-DIDO Combination Basket
LWT 315-40-156, Rev. 3 (Sheets 1-4)	Canister Assembly SLOWPOKE Fuel
LWT 315-40-158, Rev. 0	Legal Weight Truck Transport Cask Assy, SLOWPOKE Fuel
LWT 315-40-170, Rev. 1	LWT Transport Cask Assy., AECL NRU/NRX Components
LWT 315-40-172, Rev. 0 (Sheets 1-2)	Lid Assembly, NRU/NRX
LWT 315-40-173, Rev. 0 (Sheets 1-2)	Basket Weldment, NRU/NRX
LWT 315-40-174, Rev. 0	Basket Spacer, NRU/NRX
LWT 315-40-175, Rev. 1	Caddy Assembly, NRU/NRX
LWT 315-40-180, Rev. 1P & 0NP	LWT Transport Cask Assembly, HEUNL Contents
LWT 315-40-181, Rev. 1P & 0NP	Container Assembly, HEUNL
LWT 315-40-182, Rev. 1P & 0NP	Container Spacer, HEUNL
LWT 315-40-183, Rev. 1P & 0NP	Container Guide, HEUNL

5.(b) Contents

(1) Type and form of material

All contents listed include both unirradiated and irradiated conditions.

(i) PWR fuel assemblies. The maximum fuel assembly weight is 1650 pounds, the maximum average burnup is 35,000 MWd/MTU, the minimum cool time is 2 years, and the maximum initial fuel pin pressure at 70°F is 565 psig. The fuel assemblies consist of uranium dioxide pellets within zirconium alloy type cladding, with the specifications listed below, and with fuel rod pitch, rod diameter, clad thickness, and pellet diameter as described in Table 1.2-5, of the application.

Fuel Type	No. Fuel Rods	Max. Initial Uranium Enrichment (wt % U235)	Max. Initial Uranium Mass (MTU)	Max. Active Fuel Length (in.)
B&W 15x15	208	3.5	0.4750	144.0
B&W 17x17	264	3.5	0.4658	143.0
CE 14x14	176	3.7	0.4037	137.0
CE 16x16	236	3.7	0.4417	150.0
WE 14x14 Std	179	3.7	0.4144	145.2
WE 14x14 OFA	179	3.7	0.3612	144.0
WE 15x15	204	3.5	0.4646	144.0
WE 17x17 Std	264	3.5	0.4671	144.0

5.(b)(1)(i) PWR fuel assemblies. (continued)

WE 17x17 OFA	264	3.5	0.4282	144.0
Ex/ANF 14x14 WE	179	3.7	0.3741	144.0
Ex/ANF 14x14 CE	176	3.7	0.3814	134.0
Ex/ANF 15x15 WE	204	3.7	0.4410	144.0
Ex/ANF 17x17 WE	264	3.5	0.4123	144.0

(ii) BWR fuel assemblies. The maximum fuel assembly weight is 750 pounds, the maximum average burnup is 30,000 MWd/MTU, the minimum cool time is 2 years, and the maximum initial fuel pin pressure at 70°F is 565 psig. The fuel assemblies consist of uranium dioxide pellets within zirconium alloy type cladding, with the specifications listed below, and with fuel rod pitch, rod diameter, clad thickness, and pellet diameter as described in Table 1.2-6, of the application.

Fuel Type	No. Fuel Rods	No. Water Rods	Max. Initial Uranium Enrichment (wt % U-235)	Max. Initial Uranium Mass (MTU)	Max. Active Fuel Length (in.)
GE 7x7	49	0	4.0	0.1923	146
GE 8x8-1	63	1	4.0	0.1880	146
GE 8x8-2	62	2	4.0	0.1847	150 (1)
GE 8x8-4	60	4	4.0	0.1787	150 (1,2)
GE 9x9	74	2	4.0	0.1854	150 (1,3,4)
	79	2	4.0	0.1979	150 (1,4)
Ex/ANF 7x7	49	0	4.0	0.1960	144
Ex/ANF 8x8-1	63	1	4.0	0.1764	145.2
Ex/ANF 8x8-2	62	2	4.0	0.1793	150
Ex/ANF 9x9	79	2	4.0	0.1779	150
	74	2	4.0	0.1666	150 (3)

(1) Six-inch natural uranium blankets on top and bottom.
(2) One large water hole - 3.2 cm ID, 0.1 cm thickness.
(3) Two large water holes occupying seven fuel rod locations - 2.5 cm ID, 0.07 cm thickness.
(4) Shortened active fuel length in some rods.

5.(b)(1) Type and form of material (continued)

(iii) Deleted.

(iv) MTR fuel elements composed of U-Al, U_3O_8-Al, or U_3Si_x-Al positioned within the MTR fuel basket specified in 5.(a)(3)(ii). Loose fuel plates must meet the requirements of the MTR fuel element content tables and must be loaded into an MTR plate canister prior to shipment. The fuel elements are composed of aluminum clad plates, with initial uranium enrichment up to 94.0 weight percent U-235. The maximum burnup and the minimum cool time shall be consistent with the decay heat limits in Item 5.(b)(2)(iv) and shall be determined using the operating procedures in Section 7.1.5 of the application.

NISTR MTR fuel elements specifications are listed in Item 5.(b)(1)(iv)(a), generic MTR fuel elements are listed in Item 5.(b)(1)(iv)(b), and expanded fuel specifications applicable to LEU MTR fuel (up to 25.0 wt %^{235}U) are listed in Items 5.(b)(1)(iv)(c) and 5.(b)(1)(iv)(d).

(a) NISTR MTR Fuel Content Description

Parameter	Plate	Plate (cut in half)
Enrichment, wt % ^{235}U	≤94	
Number of fuel plates	≤1[illegible]	≤34
^{235}U content per plate	≤22	≤11
Plate thickness (cm)	≥0.115	
Clad Thickness (cm)	≥0.02	
Active fuel width (cm)	≤6.6	
Active fuel height (cm)	≥54 cm	27 to 30
Maximum ^{235}U content per element (g)	≤380	

5.(b)(1) Type and form of material (continued)

(iv) (b) Generic MTR Fuel Content Description

Parameter	Limiting Values[2, 3]					
Enrichment, wt. % ^{235}U	≤94					
Number of fuel plates	≤23	≤19	≤23[1]	≤17	≤19	≤23
^{235}U content per plate	≤18	≤20	≤20[1]	≤21	≤21	≤16.5
Plate thickness (cm)	≥0.115	≥0.115	≥0.123[1]	≥0.115	≥.200	≥0.115
Clad Thickness (cm)	≥0.02					
Active fuel width (cm)	≤6.6	≤6.6	≤6.6	≤6.6	≤6.6	≤7.3
Active fuel height (cm)	≥56[3]					
^{235}U content per element (g)	≤380[2]					

Notes:

1. HEU (>90 wt% ^{235}U enriched) MTR fuel having 23 plates with up to 20 g of ^{235}U per plate, with a minimum plate thickness of 0.123 cm, must have at least 2.0 cm of non-fuel material at the ends of each element. This fuel may also be loaded up to 460 g ^{235}U per element.

2. At enrichments ≤25 wt% ^{235}U, MTR fuel elements with extended fuel characteristics may be loaded with the specifications defined in 5.(b)(1)(iv)(c).

3. Reduced active fuel height is permissible for loading provided that the ^{235}U content per plate and ^{235}U content per assembly is proportionally reduced (e.g. a ≤ 7.13 cm active fuel height element is authorized for loading at a minimum of 42 cm active fuel height provided the maximum ^{235}U content per plate is ≤ 12.375 g, 16.5 × 42/56 and ^{235}U content per assembly is ≤ 285 g, 380 × 42/56).

5.(b)(1) Type and form of material (continued)

(iv) (c) Expanded LEU MTR Fuel Content Description

Parameter	Base	≤7.0 cm Active Fuel Width			≤7.1 cm Active Fuel Width		≤7.15 cm Active Fuel Width		
Enrichment, wt. % ^{235}U	≤25	≤25			≤25		≤25		
Number of fuel plates	≤23	≤23			≤17	≤23	≤22	≤23	≤23
^{235}U content per plate	≤22	≤22	≤22	≤21.5	≤22		≤22	≤21.5	≤22
Plate thickness (cm)	≥0.115	≥0.119	≥0.115	≥0.115	≥0.115	≥0.200	≥0.119		
Clad Thickness (cm)	≥0.02								
Active fuel width (cm)	≤6.6	≤7.0			≤7.1		≤7.15		
Active fuel height (cm)	≥56	≥56	≥63	≥56	≥56		≥56	≥56	≥61
^{235}U content per element (g)	≤420	≤470			≤470		≤470		

5.(b)(1) Type and form of material (continued)

(iv) (d) Expanded LEU MTR Fuel Content Description for High Fissile Material Mass

Parameter	Limiting Value
Enrichment, wt.% ^{235}U	≤25
Number of fuel plates	≤23
^{235}U content per plate (g)	≤32
Plate thickness (cm)	≥0.115
Clad thickness (cm)	≥0.02
Active fuel width (cm)	≤7.3
Active fuel height (cm)	≥56
^{235}U content per element (g)	≤640

(v) Metallic fuel rods containing natural enrichment uranium pellets with aluminum cladding 0.080-inches thick. The fuel pellet diameter is 1.36 inches and the maximum fuel rod length is 120.5 inches. The maximum weight of uranium per rod is 54.5 kg with a maximum average burnup of 1,600 MWd/MTU and a minimum cooling time of one year.

(vi) TRIGA damaged and undamaged fuel elements. TRIGA fuel elements that have a cladding breach that allows the escape of gas or intrusion of water are considered damaged and will be loaded and transported in a sealed damaged fuel can.

5.(b)(1) Type and form of material (continued)

(vi) (a) TRIGA fuel elements acceptable for loading in the poisoned TRIGA basket and meeting the following specifications:

	TRIGA HEU (Notes 1, 2, 6, & 7)	TRIGA LEU (Notes 1, 2, 6, & 7)	TRIGA LEU (Notes 1, 2, 6, & 7)
Fuel Form	Clad U-ZrH rod	Clad U-ZrH rod	Clad U-ZrH rod
Maximum Element Weight, lbs	13.2	13.2	13.2
Maximum Element Length, in	47.74	47.74	47.74
Element Cladding	Stainless Steel	Stainless Steel	Aluminum
Clad Thickness, in	0.02	0.02	0.03
Active Fuel Length, in	15	15	14-15 (Note 4)
Element Diameter, in	1.478 max.	1.478 max.	1.47 max.
Fuel Diameter, in	1.435 max.	1.435 max.	1.41 max.
Maximum Initial U Content/Element, kilograms	0.196	0.845	0.205
Maximum Initial ^{235}U Mass, grams	137	169	41
Maximum Initial ^{235}U Enrichment, weight percent	70	20	20
Zirconium Mass, grams (Note 5)	2060	1886 – 2300	2300
Hydrogen to Zirconium Ratio, max. (Note 5)	1.6	1.7	1.0
Maximum Average Burnup, MWd/MTU	460,000 (80% ^{235}U)	151,100 (80% ^{235}U)	151,100 (80% ^{235}U)
Minimum Cooling Time	90 days (Note 3)	90 days (Note 3)	90 days (Note 3)

Notes:

1. Mixed TRIGA LEU and HEU contents authorized.
2. TRIGA Standard, instrumented and fuel follower control rod type elements authorized.
3. Maximum decay heat of any element is 7.5 watts.
4. Aluminum clad fuel with 14 inch active fuel is solid and has no central hole with a zirconium rod.
5. Zirconium mass and H/Zr ratio apply to the fuel material (U-Zr-H$_x$) and do not include the center zirconium rod.
6. Listed TRIGA fuel elements have a 0.225-inch diameter zirconium rod in the center.
7. Dimensions listed are as-fabricated (unirradiated) nominal values.

5.(b)(1) Type and form of material (continued)

(vi) (b) TRIGA fuel elements acceptable for loading in the nonpoisoned TRIGA basket and meeting the following specifications:

	TRIGA HEU (Notes 1, 2, & 6)	TRIGA LEU (Notes 1, 2, & 6)	TRIGA LEU (Notes 1, 2, & 6)
Fuel Form	Clad U-ZrH rod (Note 4)	Clad U-ZrH rod (Note 4)	Clad U-ZrH rod (Note 4)
Maximum Element Weight, lbs	13.2	13.2	13.2
Maximum Element Length, in	47.74	47.74	47.74
Element Cladding	Stainless Steel	Stainless Steel	Aluminum
Minimum Clad Thickness, in	0.01	0.01	0.01
Maximum Element Diameter, in	1.5 max	1.5 max.	1.5 max.
Active Fuel Length, in	15	15	15
Maximum Initial U Content/Element, kilograms	0.196	0.845	0.205
Maximum Initial ^{235}U Mass, grams	137	169	41
Maximum Initial ^{235}U Enrichment, weight percent	70	20	20
Hydrogen to Zirconium Ratio, max. (Note 5)	2.0	2.0	2.0
Maximum Average Burnup, MWd/MTU	460,000 (80% ^{235}U)	151,100 (80% ^{235}U)	151,100 (80% ^{235}U)
Minimum Cooling Time	90 days (Note 3)	90 days (Note 3)	90 days (Note 3)

Notes:

1. Mixed TRIGA LEU and HEU contents authorized.
2. TRIGA Standard, instrumented and fuel follower control rod type elements authorized.
3. Maximum decay heat of any element is 7.5 watts.
4. Element may contain a zirconium rod in the center.
5. H/Zr ratio applies to the fuel material (U-Zr-H_x) and does not include the center zirconium rod.
6. Dimensions listed are as-fabricated (unirradiated) nominal values.

5.(b)(1) Type and form of material (continued)

(vi) (c) General Atomics TRIGA fuel elements acceptable for loading in the nonpoisoned TRIGA basket and meeting the following specifications:

	TRIGA HEU (Notes 1, 2, & 6)		TRIGA LEU (Notes 1, 2, & 6)		TRIGA LEU (Notes 1, 2, & 6)
Fuel Form	Clad U-ZrH rod (Note 4)		Clad U-ZrH rod (Note 4)		Clad U-ZrH rod (Note 4)
Maximum Element Weight, lbs	13.2		13.2		13.2
Maximum Element Length, in	47.74		47.74		47.74
Element Cladding	Stainless Steel		Stainless Steel		Aluminum
Minimum Clad Thickness, in	0.01		0.01		0.01
Maximum Element Diameter, in	1.5 max.		1.5 max.		1.5 max.
Active Fuel Length, in	15		15		15
Maximum Initial U Content/Element, kilograms	0.198	0.[illegible]86	0.845	1.447	0.205
Maximum Initial ^{235}U Mass, grams	38	[illegible]5^{7,8}	169	275^{7,8}	41
Maximum Initial ^{235}U Enrichment, weight percent	[illegible]	95^{7,8}	25	25^{7,8}	25
Hydrogen to Zirconium Ratio, max. (Note 5)	2.0		2.0		2.0
Maximum Average Burnup, MWd/MTU	460,000 (80% ^{235}U)	583,000 (80% ^{235}U)	151,100 (80% ^{235}U)		151,100 (80% ^{235}U)
Minimum Cooling Time	90 days (Note 3)		90 days (Note 3)		90 days (Note 3)

Notes:

1. Mixed TRIGA LEU and HEU fuel elements and LEU and HEU TRIGA fuel cluster rod contents authorized.
2. TRIGA Standard, instrumented and fuel follower control rod type elements authorized.
3. Maximum decay heat of any element is 7.5 watts.
4. Element may contain a zirconium rod in the center.
5. H/Zr ratio applies to the fuel material (U-Zr-H_x) and does not include the center zirconium rod.

[illegible] Dimensions listed are as-fabricated (unirradiated) nominal values.

[illegible] Limited to loading in top and bottom basket modules only.

8. Limited to a maximum of three elements per basket module cell.

5.(b)(1) Type and form of material (continued)

(vii) (a) TRIGA fuel cluster rods. TRIGA HEU fuel cluster rods have a maximum average burnup of 600,000 MWd/MTU (80% ^{235}U depletion) and a minimum cooling time of 90 days. TRIGA LEU fuel cluster rods have a maximum average burnup of 140,000 MWd/MTU (80% ^{235}U depletion) and a minimum cooling time of 90 days. TRIGA fuel cluster rods must meet the following specifications prior to irradiation:

	TRIGA Fuel Cluster Rods	
	HEU	LEU
Fuel Form	Clad U-ZrH rod	
Maximum Rod Weight, lbs	1.5	
Maximum Rod Length, in	31	
Rod Cladding	Incoloy 800	
Minimum Clad Thickness, in	0.015	
Maximum Active Fuel Length, in	22.5	
Maximum Fuel Pellet Diameter, in	0.53	
Maximum U Content/Rod, grams	48.6	289.5
Maximum ^{235}U Mass, grams	45.4	55.0
Maximum ^{235}U Enrichment, weight percent	93.3	20
Maximum Zirconium Mass, grams	421	357
Hydrogen to Zirconium Ratio, max.	1.7	

NOTE: TRIGA fuel cluster rods that have a cladding breach that allows the escape of gas or intrusion of water are considered damaged and will be loaded and transported in a sealed damaged fuel can.

5.(b)(1) Type and form of material (continued)

(vii) (b) General Atomics TRIGA fuel cluster rods. TRIGA HEU fuel cluster rods have a maximum average burnup of 600,000 MWd/MTU (80% ^{235}U depletion) and a minimum cooling time of 90 days. TRIGA LEU fuel cluster rods have a maximum average burnup of 140,000 MWd/MTU (80% ^{235}U depletion) and a minimum cooling time of 90 days. TRIGA fuel cluster rods must meet the following specifications prior to irradiation:

	TRIGA Fuel Cluster Rods	
	HEU	LEU
Fuel Form	Clad U-ZrH rod	
Maximum Rod Weight, lbs	1.5	
Maximum Rod Length, in	31	
Rod Cladding	Incoloy 800	
Minimum Clad Thickness, in	0.015	
Maximum Active Fuel Length, in	22.5	
Maximum Fuel Pellet Diameter, in	0.53	
Maximum U Content/Rod, grams	48.6	289.5
Maximum ^{235}U Mass, grams	46.5	55.0
Maximum ^{235}U Enrichment, weight percent	93.3	20
Maximum Zirconium Mass, grams	421	357
Hydrogen to Zirconium Ratio, max.	1.7	

NOTE: TRIGA fuel cluster rods that have a cladding breach that allows the escape of gas or intrusion of water are considered damaged and will be loaded and transported in a sealed damaged fuel can.

(viii) High burnup PWR rods, consisting of uranium dioxide pellets within zirconium alloy type cladding. The maximum uranium enrichment is 5 weight percent U-235, the maximum active fuel length is 150 inches, and the maximum pellet diameter is 0.3765 inches. The maximum burnup is 80,000 MWd/MTU, and the minimum cool time is 150 days.

5.(b)(1) Type and form of Material (continued)

(ix) High burnup BWR rods, consisting of uranium dioxide pellets within zirconium alloy type cladding. The maximum uranium enrichment is 5 weight percent U-235, the maximum active fuel length is 150 inches, and the maximum pellet diameter is 0.490 inch. The maximum burnup is 80,000 MWd/MTU and the minimum cool time is between 150 - 270 days, as specified in the table below:

BWR Fuel Type Array Size	Burnup, b (GWd/MTU)	Minimum Cool Time (days)
7 x 7	$b \leq 60$	210
	$60 < b \leq 70$	240
	$70 < b \leq 80$	270
8 x 8[1]	$b \leq 80$	150

Note 1: Includes rods from all larger BWR assembly arrays (e.g., 9 x 9, 10 x 10)

(x) Intact or degraded clad DIDO fuel elements composed of U-Al, U_3O_8-Al, or U_3Si_x-Al plates fabricated into four concentric tubes of varying diameters. The fuel elements have an initial enrichment up to 94.0 weight percent U-235. Maximum degraded clad allowable per element is ≤ 5% surface area. Degraded clad DIDO fuel elements are to be loaded into an aluminum damaged fuel can (DFC) per Figure 1.2.3-18 of the application. The fuel elements shall have the specifications listed below:

Parameter	LEU(1)	MEU(1)	HEU(1)
Maximum ^{235}U content per Element	≤ 190 g	≤ 190 g	≤ 190 g
Maximum Uranium content per Element	≤ 1000 g	≤ 475.0 g	≤ 211.1g
Minimum Fuel Tube Thickness	0.130 cm	0.130 cm	0.130 cm
Minimum Clad Thickness	0.025 cm	0.025 cm	0.025 cm
Maximum Outer Diameter	9.535 cm	9.535 cm	9.535 cm
Minimum Inner Diameter	5.88 cm	5.88 cm	5.88 cm
Minimum Initial Enrichment	19 wt% ^{235}U	40 wt% ^{235}U	90 wt% ^{235}U

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[1] The maximum burnup and minimum cool time shall be consistent with the decay heat limits in Item 5.(b)(2)(xi)(a) and (b) and shall be determined using the operating procedures in Section 7.1.4 of the application.

5.(b)(1) Type and form of material (continued)

(xi) General Atomics (GA) Irradiated Fuel Material (IFM) consisting of two separate types of fuel materials: (a) High Temperature Gas Cooled Reactor (HTGR); and (b) Reduced-Enrichment Research and Test Reactor (RERTR) type TRIGA fuel entities.

(a) GA HTGR IFM comprised of four forms: fuel particles (kernels), fuel particles (coatings), fuel compacts (rods), and fuel pebbles. Fuel particles (kernels) are solid, spheridized, high-temperature sintered fully-densified, ceramic kernel substrate, composed of UO_2, UCO_2, $(Th,U)C_2$, or $(Th,U)O_2$. Fuel particles (coatings) are solid , spheridized, isotropic, discrete multi-layered fuel particle coatings with chemical composition including pyrolitic-carbon (PyC) and silicon carbide (SiC). Fuel compacts (rods) are multi-coated ceramic fuel particles, bound in solid, cylindrical, injection molded, high-temperature heat-treated compacts which are composed of carbonized graphite shim, coke, and graphite powder. Fuel pebbles are multi coated fuel particles, bound in solid, spherical injection-molded, high-temperature heat-treated pebbles composed of carbonized graphite shim, coke, and graphite powder. Initial enrichment of the HTGR IFM varies from 10.0 to 93.15 wt% ^{235}U.

(b) GA RERTR IFM comprised of irradiated TRIGA fuel elements which contain three distinct mass loadings of uranium of 20, 30, and 45 wt% U. The average mass of the fuel portion of the elements is 551 g with a maximum initial enrichment of 19.7 wt% U-235.

GA IFM content description:

	GA HTGR IFM	GA RERTR IFM
Fuel material	UC_2, UCO, UO_2 $(Th,U)C_2$, $(Th,U)O_2$	U-ZrH metal alloy
Maximum fuel weight, lbs	23.52	23.73
Maximum overall length, in	n/a	29.92
Maximum active fuel length, in	n/a	22.05
Fuel rod cladding	n/a	Incoloy 800
Maximum Uranium, kg U	0.21	3.86
Maximum initial ^{235}U, wt%	93.15	19.7
Maximum Activity, Ci	483	2920

5.(b)(1) Type and form of material (continued)

(xii) Tritium-producing burnable absorber rods (TPBARs), as described in Section 1.2.3.6 of the application. Each TPBAR is approximately 153 inches in length and 0.381 inches in diameter and is stainless steel clad. The TPBARs contain lithium aluminate annular pellets, with an inner zircaloy liner and an outer nickel-plated zircaloy tube. Each TPBAR contains a maximum of 1.2 grams tritium. The minimum cool time is 30 days.

(xiii) Intact or damaged PULSTAR fuel elements, including fuel debris, pieces and nonfuel components of PULSTAR fuel assemblies as specified below.

Description	Value
Maximum Pellet Diameter (inch)	0.423
Minimum Element (Rod) Cladding Thickness (inch)	0.0185
Minimum Element (Rod) Diameter (inch)	0.470
Maximum Active Fuel Height (inch)	24.1
Nominal Element (Rod) Length (inch)	26.2
Nominal Assembly Length (inch)	38
Maximum Assembly or Loaded Can Weight (lb)	80
Maximum PULSTAR Can Content Weight (lb)	39.6
Maximum Enrichment (wt % ^{235}U)	6.5
Maximum ^{235}U Content per Element (g)	33
No. of Elements (Rods) per Assembly	25
No. of Elements (Rods) per Can[1]	≤25
Maximum Depletion (% ^{235}U)	45
Minimum Cooling Time (yrs)	1.5
Maximum Heat Load per Assembly (W)	30
Maximum Heat Load per Element (W)	1.2

[1] Damaged PULSTAR fuel elements, including fuel debris, pieces and nonfuel components of PULSTAR fuel assemblies must be loaded into a PULSTAR can. The contents of a PULSTAR can are restricted to the equivalent of the fuel material in 25 intact PULSTAR fuel elements and of the displaced volume of 25 intact PULSTAR fuel elements.

5.(b)(1) Type and form of material (continued)

(xiv) Intact or degraded clad ANSTO fuel consisting of spiral fuel assemblies and MOATA plate bundles. Maximum degraded clad allowable per element is ≤ 5% surface area. Degraded clad ANSTO fuel elements are to be loaded into an aluminum damaged fuel can (DFC) per Figure 1.2.3-18 of the application.

Spiral fuel assemblies consist of 10 curved uranium-aluminum alloy fuel plates between an inner and an outer aluminum shell, with the following fuel parameters:

Parameter	Limiting Values
Number of fuel plates per assembly	10
Maximum ^{235}U content per assembly (g)	160
Maximum enrichment (wt % ^{235}U)	95
Maximum assembly weight (lb)	18
Minimum plate thickness (cm)	0.124
Minimum active fuel height (cm)	59.075

MOATA plate bundles consist of uranium-aluminum alloy fuel plates with aluminum cladding, with the following specifications:

Parameter	Limiting Values
Maximum number of fuel plates per assembly	14
Maximum ^{235}U content per plate (g)	22.3
Maximum enrichment (wt % ^{235}U)	92
Maximum plate spacer thickness (cm)	0.18
Maximum active fuel width (cm)	7.32
Maximum bundle weight (lb)	18

(xv) Segmented TPBARs and associated segmentation debris resulting from post-irradiation examination, as described in Section 1.2.3.6 of the application. Each equivalent TPBAR contains a maximum of 1.2 grams of tritium. The minimum cool time is 90 days.

(xvi) Solid, irradiated and contaminated fuel assembly structural or reactor internal component hardware, which may include fissile material, provided the quantity of fissile material does not exceed a Type A quantity and qualifies as an exempt quantity under 10 CFR 71.15.

5.(b)(1) Type and form of material (continued)

(xvii) PWR MOX (mixed oxide) undamaged fuel rods consisting of uranium and plutonium and plutonium dioxide pellets within zirconium alloy type cladding. The plutonium enrichment is 7.0 weight percent maximum and 2.0 weight percent minimum, the maximum active fuel rod length is 153.5 inches, and the maximum pellet diameter is 0.3765 inch. The maximum burnup is 62,500 MWd/MTU and the minimum cool time is 90 days.

(xviii) Damaged or undamaged SLOWPOKE fuel rods, including fuel pieces and debris as specified below:

Parameter	Limiting Values
Maximum Cask Heat Load (W)	5
Maximum Canister Heat Load (W)	0.25
Payload Limit (lb/canister)	25
Maximum ^{235}U per rod (g)	2.800
Maximum U per rod (g)	3.111
Maximum Enrichment (wt% ^{235}U)	95
Minimum cool time (yr)	14
Maximum burnup (GWd/MTU or	30
wt% ^{235}U Depletion	4.5

(xix) Undamaged NRU or NRX fuel assemblies as specified below:

Parameter	NRU (HEU)	NRU (LEU)	NRX
Maximum Cask Heat Load (W)	640.0		
Maximum Per Tube Heat Load (W)	35.6		
Payload Limit (lb/tube)	20.0		
Maximum ^{235}U per rod (g)	43.24	43.68	79.05
Maximum U per rod (g)	48	230	87
Minimum cool time (yr)	19	3	18
Maximum burnup (MWd or	364.0	363.0	375.0
wt% ^{235}U Depletion	87.4	83.6	85.1

(xx) HEUNL as specified below:

Parameter	Liquid HEU
Maximum HEUNL payload per Container	64.3 L (17.0 gal)
Maximum Cask Heat Load	12.88 W
Maximum Per Container Heat Load	3.22 W
Maximum HEUNL Heat Load	0.05 W/L
Maximum Curie Content (gamma emitters)	9.0 Ci/L
Maximum ^{235}U content	7.2 gU/L

5.(b)(2) Maximum quantity of material per package

Not to exceed 4,000 pounds, including contents and fuel assembly basket or other internal support structure.

(i) For the contents described in Item 5.(b)(1)(i): one PWR assembly positioned within the PWR fuel assembly basket. Maximum decay heat not to exceed 2.5 kilowatts per PWR assembly.

(ii) For the contents described in Item 5.(b)(1)(ii): two BWR assemblies positioned within the BWR fuel assembly basket. Maximum decay heat not to exceed 1.1 kilowatts per BWR assembly.

(iii) Deleted.

(iv) For MTR fuel elements as described in Item 5.(b)(1)(iv):

Up to 42 fuel elements positioned within the MTR fuel assembly basket (7 fuel elements per basket module). Each of the MTR basket cell openings may contain a loose plate canister. The contents of each loose plate canister are limited to the number of fuel plates, dimensions, and masses that are equivalent to an intact MTR fuel element, as specified in Item 5.(b)(1)(iv).

(a) The maximum decay heat is not to exceed 1.26 kilowatts per package, with each MTR fuel assembly basket module not to exceed 210 watts.

(b) HEU, MEU, and LEU MTR fuel elements with decay heat not exceeding 30 watts per element may be loaded in any basket position.

(c) Mixed HEU, MEU, and LEU MTR contents, with decay heat limits as specified above, are authorized.

(d) MTR fuel elements with degraded or mechanically damaged cladding are authorized, provided the total surface area of through-clad corrosion and/or mechanical damage does not exceed 5% of the total surface area of the damaged element.

(e) For HEU-MTR fuel elements only, the center fuel element in any basket module is not to exceed 120 watts. The two exterior fuel elements vertically in-line with the center assembly for transport are not to exceed 70 watts.

(f) MTR fuel elements containing more than 470 g ^{235}U (more than 22 g ^{235}U per plate) are limited to up to four elements loaded in basket positions 4, 5, 6, and 7 of a seven-element basket per Figure 7.1-1 of the application. Basket positions 1, 2, and 3 are to be blocked by spacer hardware.

(v) For the contents described in Item 5.(b)(1)(v): up to 15 intact metallic fuel rods positioned within the appropriate basket. Maximum decay heat not to exceed 0.036 kilowatts per rod. Total weight of all rods not to exceed 1,805 pounds.

5.(b)(2) Maximum quantity of material per package (continued)

(vi) For failed metallic fuel rods of the type described in Item 5.(b)(1)(v):

(a) Up to six canisters containing one defective metallic fuel rod per canister. The canisters are 2.75-inch I.D. failed fuel rod canisters as shown on Nuclear Assurance Corporation Drawing No. 340-108-D2, Rev. 10, and are placed in a six-hole liner as shown on Nuclear Assurance Corporation Drawing No. 315-040-43, Rev. 1. The maximum decay heat load for a defective metallic fuel rod is limited to 5 watts; or

(b) Up to three canisters containing either up to three defective metallic fuel rods per canister or up to 10 failed fuel filters per canister. The canisters are 4.00-inch I.D. failed fuel rod canisters as shown on Nuclear Assurance Corporation Drawing No. 340-108-D1, Rev. 10, and are placed in a three-hole basket as shown on Nuclear Assurance Corporation Drawing No. 315-40-12, Rev. 3. The weight of the filters is limited to 125 pounds per canister. For canisters containing fuel rods, the maximum decay heat load is 15 watts per canister; and for canisters containing filters, the maximum decay heat load is 5 watts per canister.

(vii)(a) For TRIGA fuel elements as described in Item 5.(b)(1)(vi)(a):

Up to 140 intact fuel elements in the TRIGA fuel package with poisoned baskets. Up to four fuel elements per basket cell and up to seven cells per basket may be loaded. Damaged TRIGA fuel elements or fuel element debris (up to a total of two equivalent elements) shall be transported in a sealed damaged fuel can (one damaged fuel can per cell). The sealed cans are to be in accordance with NAC International Drawing Nos. 315-40-086, 315-40-087, and 315-40-088.

Mixed intact and damaged fuel contents and fuel debris are authorized. Base and top fuel basket modules may contain intact fuel elements or sealed damaged fuel cans containing damaged fuel and fuel debris. A maximum of seven damaged fuel cans is authorized per top and base basket modules with a maximum of 14 per package. Intermediate fuel basket modules may contain only intact TRIGA fuel elements.

The maximum decay heat shall not exceed 7.5 watts per TRIGA fuel element (or equivalent for damaged fuel) and 1050 watts per package. The cask and baskets must be configured as shown in NAC International Drawing Nos. 315-40-084, 315-40-080, 315-40-081, and 315-40-082.

(vii)(b) For TRIGA fuel elements as described in Item 5.(b)(1)(vi)(b):

Up to 120 intact fuel elements in the TRIGA fuel package with non-poisoned basket. Up to four fuel elements per basket cell only loaded in the six periphery cells. TRIGA fuel elements or sealed cans may not be loaded in the center cell of the non-poisoned basket. Damaged TRIGA fuel elements or fuel debris (up to two equivalent elements) shall be transported in a sealed damaged fuel can (one damaged fuel can per cell). The sealed cans are to be in accordance with NAC International Drawing Nos. 315-40-086, 315-40-087, and 315-40-088.

5.(b)(2) Maximum quantity of material per package (continued)

Mixed intact and damaged fuel contents and fuel debris are authorized. Base and top fuel basket modules may contain intact fuel elements or sealed damaged fuel cans containing damaged fuel or fuel debris. A maximum of six damaged fuel cans is authorized only in the periphery cells per top and base basket modules with a maximum of 12 per package. Intermediate fuel basket modules may contain only intact TRIGA fuel elements.

Maximum decay heat not to exceed 7.5 watts per TRIGA fuel element (or equivalent for damaged fuel) and 900 watts per package. Fuel may not be loaded in the center cell of the non-poisoned TRIGA fuel basket. The cask and baskets must be configured as shown in NAC International Drawing Nos. 315-40-070, 315-40-071, and 315-40-072, and 315-40-079.

(vii)(c) For General Atomics TRIGA fuel elements as described in Item 5.(b)(1)(vi)(c):

Up to 120 intact fuel elements in the TRIGA fuel package with non-poisoned basket. Up to four fuel elements per basket cell only loaded in the six periphery cells. TRIGA fuel elements or sealed cans may not be loaded in the center cell of the non-poisoned basket. Damaged TRIGA fuel elements or fuel debris (up to two equivalent elements of maximum 1.5 inch diameter) shall be transported in a sealed damaged fuel can (one damaged fuel can per cell). The sealed cans are to be in accordance with NAC International Drawing Nos. 315-40-086, 315-40-087, and 315-40-088.

Loading of TRIGA HEU and LEU fuel elements having >138 g and >169 g initial ^{235}U mass contents, respectively, are limited to top and bottom basket modules and up to three rods per basket cell. A minimum of one TRIGA dummy rod per NAC Drawing No. 315-40-085 shall be installed in place of a TRIGA fuel element to limit the maximum number of rods per cell to three.

Mixed loading in separate cells of TRIGA fuel elements and TRIGA fuel cluster rods [per 5.(b)(1)(vii)(b)] is authorized in fuel basket modules with the content quantities limited in accordance with the other conditions and limitations of 5.(b)(2)(vii)(c) and 5.(b)(2)(viii)(b).

Maximum decay heat not to exceed 7.5 watts per TRIGA fuel element (or equivalent for damaged fuel) and 900 watts per package. Fuel may not be loaded in the center cell of the non-poisoned TRIGA fuel basket. The cask and baskets must be configured as shown in NAC International Drawing No. 315-40-079.

5.(b)(2) Maximum quantity of material per package (continued)

(viii)(a) For TRIGA fuel cluster rods as described in Item 5.(b)(1)(vii)(a):

Maximum decay heat not to exceed 1.875 watts per TRIGA fuel cluster rod (or equivalent for failed fuel) and 1050 watts per package. TRIGA fuel cluster rods must be positioned in either the non-poisoned TRIGA fuel basket or in the poisoned TRIGA fuel basket. Fuel may not be loaded in the center cell of the non-poisoned TRIGA fuel basket. The non-poisoned basket must be configured as shown in NAC International Drawing Nos. 315-40-070, 315-40-071, and 315-40-072, and the poisoned basket must be configured as shown in NAC International Drawing Nos. 315-40-080, 315-40-081, and 315-40-082.

Up to 480 intact cluster rods per package in the non-poisoned TRIGA fuel baskets (up to six periphery cells loaded with 16 cluster rods each), and up to 560 intact cluster rods per package in the poisoned TRIGA fuel baskets (up to 7 total cells loaded with 16 cluster rods each). TRIGA fuel cluster rods must be positioned within the fuel rod inserts as shown on NAC International Drawing No. 315-40-096.

Damaged TRIGA fuel cluster rod or cluster rod debris (up to six equivalent rods) shall be transported in a sealed damaged fuel can. The sealed cans are to be in accordance with NAC International Drawing Nos. 315-40-086, 315-40-087, and 315-40-088.

Mixed intact and damaged fuel contents and fuel debris are authorized. Base and top fuel basket modules may contain intact fuel cluster rods or sealed DFCs. Intermediate fuel basket modules may contain only intact fuel cluster rods.

(viii)(b) For TRIGA fuel cluster rods as described in Item 5.(b)(1)(vii)(b):

Maximum decay heat not to exceed 1.875 watts per TRIGA fuel cluster rod (or equivalent for failed fuel) and 1050 watts per package. TRIGA fuel cluster rods must be positioned in the non-poisoned TRIGA fuel basket. Fuel may not be loaded in the center cell of the non-poisoned TRIGA fuel basket. The non-poisoned basket must be configured as shown in NAC International Drawing Nos. 315-40-070, 315-40-071, and 315-40-072.

Up to 480 intact cluster rods per package in the non-poisoned TRIGA fuel baskets (up to six periphery cells loaded with 16 cluster rods each), and up to 560 intact cluster rods per package in the poisoned TRIGA fuel baskets (up to 7 total cells loaded with 16 cluster rods each). TRIGA fuel cluster rods must be positioned within the fuel rod inserts as shown on NAC International Drawing No. 315-40-096.

5.(b)(2) Maximum quantity of material per package (continued)

Damaged TRIGA fuel cluster rods or cluster rod debris (up to six equivalent rods) shall be transported in a sealed damaged fuel can. The sealed cans are to be in accordance with NAC International Drawing Nos. 315-40-086, 315-40-087, and 315-40-088.

Mixed intact and damaged fuel contents and fuel debris are authorized. Base and top fuel basket modules may contain intact fuel cluster rods or sealed DFCs. Intermediate fuel basket modules may contain only intact fuel cluster rods.

Mixed loading in separate cells of TRIGA fuel elements [per 5.(b)(1)(vi)(c)] and TRIGA fuel cluster rods [per 5.(b)(1)(vii)(b)] is authorized in fuel basket modules with the content quantities limited in accordance with the other conditions and limitations of 5.(b)(2)(vii)(c) and 5.(b)(2)(viii)(b).

(ix) For high burnup PWR fuel rods, as described in Item 5.(b)(1)(viii): up to 25 fuel rods. Maximum decay heat not to exceed [illegible].3 kilowatts per package.

Intact individual rods may be placed either in an irradiated or unirradiated fuel assembly lattice (skeleton) or in a fuel rod insert. The PWR fuel assembly lattice must be transported in the PWR basket.

Up to 14 of the 25 fuel rods may be classified as damaged. Damaged fuel rods may include fuel debris, particles, loose pellets, and fragmented rods. Damaged fuel rods must be placed in a fuel rod insert. Damaged fuel rods may also be placed in individual failed fuel rod capsules, as shown in Figure 1.2.3-11 of the application, prior to placement in the fuel rod insert. Guide/instrument tubes and tube segments may be placed in the fuel rod insert. The fuel rod insert must be transported in a PWR/BWR transport canister, which is positioned in the PWR insert in the PWR basket.

(x) For high burnup BWR fuel rods, as described in Item 5.(b)(1)(ix): up to 25 fuel rods. Maximum decay heat not to exceed 2.1 kilowatts per package.

Intact individual rods may be placed either in a fuel assembly lattice or in a fuel rod insert. The BWR fuel assembly lattice must be transported in the PWR insert in the PWR basket.

Up to 14 of the 25 fuel rods may be classified as damaged. Damaged fuel rods may include fuel debris, particles, loose pellets, and fragmented rods. Damaged fuel rods must be placed in a fuel rod insert. Damaged fuel rods may also be placed in individual failed fuel rod capsules, as shown in Figure 1.2.3-11 of the application, prior to placement in the fuel rod insert. Water rods and inert rods may be placed in the fuel rod insert. The fuel rod insert must be transported in a PWR/BWR transport canister, which is positioned in the PWR insert in the PWR basket.

5.(b)(2) Maximum quantity of material per package (continued)

(xi) For DIDO fuel as described in Item 5.(b)(1)(x):

(a) Up to 42 DIDO fuel elements with a maximum decay heat not to exceed 25 watts per DIDO fuel element, provided the top basket fuel element active fuel region is spaced a minimum 3.7 inches from the bottom of the cask lid. Spacing of the active fuel may be accomplished by fuel element hardware, lid spacer, or a combination thereof. Maximum decay heat is 1.05 kilowatts per package. At a top basket active fuel region to cask lid spacing of less than 3.7 inches, the maximum decay heat not to exceed 18 watts per DIDO fuel element and a total of 756 watts per package. The DIDO fuel elements are to be loaded into a DIDO basket configured as shown in NAC International Drawing No. 315-40-111.

(b) A mixed fuel load of up to 42 DIDO fuel elements and spiral and MOATA fuel assemblies [per item 5.(b)(1)(xiv)] in an ANSTO-DIDO combination basket configured as shown in NAC International Drawing No. 315-40-148 consisting of a top ANSTO basket module per NAC International Drawing No. 315-40-140; four intermediate DIDO basket modules per NAC International Drawing No. 315-40-109; and one bottom DIDO basket module per NAC International Drawing No. 315-40-110. DIDO fuel elements loaded into intermediate and bottom basket modules are limited to ≤18 Watts. Up to seven degraded clad DIDO, spiral, and/or MOATA fuel assemblies in DFCs per Figure 1.2.3-18 of the application, or intact DIDO, spiral, and/or MOATA assemblies may be loaded in the top ANSTO module. The per element or DFC heat load limits for the top ANSTO module are: DIDO fuel element with or without DFC is 10 Watts; spiral fuel element in DFC is 10 Watts and 15.7W without DFC; and MOATA fuel element in DFC is 1 Watt and 3 Watts without DFC. Maximum heat load per package is 753 Watts.

(xii) For GA IFM as described in Item 5.(b)(1)(xi):

(a) Mixture of fuel particles (kernels and coatings), fuel compacts (rods), and fuel pebbles, packaged in its own Fuel Handling Unit (FHU).

GA HTGR FHU consists of two redundant canisters. GA HTGR IFM is packaged inside a primary canister with welded closure, as shown in General Atomics Drawing No. 032237, Rev. B, “HTGR Primary Enclosure.” The primary canister is packaged inside a secondary canister with welded closure, as shown in General Atomics Drawing No. 032231, Rev. A, “HTGR Secondary Enclosure.”

GA HTGR FHU total maximum decay heat not to exceed 2.05 watts, and maximum loaded weight not to exceed 71.5 lbs.

(b) Twenty irradiated TRIGA fuel elements; 13 of the elements are intact, and the remaining 7 are sectioned. GA RERTR IFM is packaged in its own FHU.

5.(b)(2) Maximum quantity of material per package (continued)

GA RERTR FHU consists of two redundant canisters. GA RERTR IFM is packaged inside a primary canister with welded closure, as shown in General Atomics Drawing No. 032236, Rev. B, "RERTR Primary Enclosure." The GA RERTR IFM primary canister is packaged inside a secondary canister with welded closure, as shown in General Atomics Drawing No. 032230, Rev. A, "RERTR Secondary Enclosure."

GA RERTR FHU total maximum decay heat not to exceed 11 watts, and maximum loaded weight not to exceed 76.0 lbs.

(xiii) For TPBARs as described in Item 5.(b)(1)(xii):

Up to 300 TPBARs, including a maximum of 2 damaged rods, positioned within a consolidation canister, as shown in Figure 1.2.3-10 of the application. The consolidation canister is transported in a TPBAR basket assembly. The maximum decay heat is 2.31 watts per rod and 693 watts per package. The maximum weight of the TPBARs and the consolidation canister is 1,000 pounds. Consolidation canisters with fewer than 300 TPBARs may also contain stainless steel spacers of various geometries. The total weight and volume of the reduced TPBAR contents plus the spacers must be less than or equal to the weight and volume of 300 TPBARs.

Up to 25 TPBARS, including a maximum of 2 prefailed rods, positioned within a PWR/BWR Rod Transport Canister. The PWR/BWR Rod Transport Canister is transported in a TPBAR basket assembly. The maximum decay heat is 2.31 watts per rod and 58 watts per package.

(xiv) For PULSTAR fuel as described in Item 5.(b)(1)(xiii):

Up to 700 intact or damaged PULSTAR fuel elements in either assembly or element form, including fuel debris, pellets, pieces and nonfuel components of PULSTAR fuel assemblies. The contents of a PULSTAR can are restricted to the equivalent of the fuel material in 25 intact PULSTAR fuel elements and of the displaced volume of 25 intact PULSTAR fuel elements.

(xv) For ANSTO fuel as described in Item 5.(b)(1)(xiv):

(a) Up to 42 spiral fuel assemblies, MOATA plate bundles, or any combination of spiral fuel assemblies and MOATA plate bundles. ANSTO fuel must be loaded within ANSTO basket modules. Spiral fuel assemblies may be cropped by removing nonfuel-bearing hardware to fit the ANSTO basket modules. Fuel assemblies that are cropped, but are otherwise intact, may be considered intact. For spiral fuel assemblies, the maximum decay heat per assembly is 15.7 watts. The minimum cool time as a function of burnup shall be consistent with the maximum decay heat limit and shall be determined using the procedures for medium enriched DIDO fuel in Section 7.1.4 of the application; the minimum cool time may not be less than 270 days. For MOATA plate bundles, the maximum heat load per bundle is 3 watts, and the minimum cool time is 10 years.

5.(b)(2) Maximum quantity of material per package (continued)

(b) A mixed fuel load of up to 42 spiral and MOATA fuel assemblies and DIDO fuel elements [per item 5.(b)(1)(x)] in an ANSTO basket configured as shown in NAC International Drawing No. 315-40-139. Degraded clad elements placed in DFCs per Figure 1.2.3-18 of the application or intact DIDO fuel elements are limited to loading in the top ANSTO basket module. Maximum heat load per DIDO element is 10W. Degraded clad spiral and MOATA fuel assemblies in DFCs are also limited to loading in the top ANSTO basket module. Spiral fuel assemblies placed into DFCs are limited to a maximum of 10W and MOATA plate bundles loaded in DFCs are limited to 1W. Spiral fuel elements not placed in DFCs are limited to 15.7 W and MOATA plate bundles not placed in DFCs are limited to a maximum of 3W with a minimum cool time of 10 years.

(xvi) For segmented TPBARs as described in Item 5.(b)(1)(xv):

Up to 55 equivalent TPBARs as segments and segmentation debris, placed within a welded waste container, as shown in Figure 1.2.3-16 of the application. The waste container is transported in a TPBAR basket assembly. The maximum decay heat is 2.31 watts per equivalent TPBAR and 27 watts per package. The maximum weight of the segmented TPBARs and the TPBAR waste container is 700 pounds.

(xvii) For solid irradiated hardware as described in Item 5.(b)(1)(xvi):

Up to 4,000 pounds, including spacers, dunnage and containers, and meeting the gamma source defined in Table 1.2-13 of the application. An irradiated hardware spacer source, per NAC Drawing No. 315-40-145, shall be installed.

(xviii) For intact PWR MOX fuel rods as described in Item 5.(b)(1)(xvii):

Up to 16 undamaged irradiated PWR MOX rods or a combination of PWR MOX and high burnup PWR fuel rods as described in Item 5.(b)(1)(viii). Maximum decay heat not to exceed 2.3 kW per package. Individual PWR MOX and PWR UO_2 fuel rods shall be placed in a 5x5 insert loaded into a screened or free flow rod canister in accordance with NAC International Drawing No. 315-40-104, for transport. Up to nine nonstainless burnable poison rods (BPRs) may be loaded in the spare locations in the 5x5 insert. The PWR/BWR fuel rod canister shall be transported in the PWR basket and the PWR insert installed in the cask cavity.

(xix) For the SLOWPOKE fuel described in Item 5.(b)(1)(xviii):

Up to 100 SLOWPOKE fuel rods (or the equivalent quantity of damaged material) may be loaded per SLOWPOKE canister in accordance with NAC Drawing No. 315-40-156 utilizing either a 4x4 or 5x5 tube array or any combination thereof. Up to 4 SLOWPOKE canisters may be loaded within a 28 MTR fuel basket module with the three center fuel cells blocked. Only the top and top intermediate fuel basket modules may be loaded with SLOWPOKE fuel. Cask configuration is to be in accordance with NAC Drawing No. 315-40-158.

5.(b)(2) Maximum quantity of material per package (continued)

(xx) For the NRU/NRX fuel described in Item 5.(b)(1)(xix):

Up to 18 undamaged NRU or NRX fuel assemblies (or the equivalent number of loose rods) may be loaded per NRU/NRX fuel basket in accordance with NAC Drawing Nos. 315-40-172, 315-40-173, 315-40-174 and 315-40-175. Package configuration to be in accordance with NAC Drawing No. 315-40-170. NRX fuel shall be placed into the fuel caddy. Placement of NRU fuel into the fuel caddy is optional. NRU and NRX fuel may not be comingled within a single package.

(xxi) For the HEUNL described in Item 5.(b)(1)(xx):

Up to 64.3 L (17.0 gal) of HEUNL may be loaded per container. A total of 4 containers per cask shall be loaded. Each container shall be at the fill capacity or shall be empty in accordance with NAC Drawing Nos. 315-40-181, 315-40-182 and 315-40-183. Dilution with a similar acid solution to achieve fill capacity is permitted. Cask configuration to be in accordance with NAC Drawing No. 315-40-180.

5(c) Criticality Safety Index (CSI)

For PWR fuel assemblies described in 5(b)(1)(i) and limited in 5(b)(2)(i)	100
For BWR fuel assemblies described in 5(b)(1)(ii) and limited in 5(b)(2)(ii)	5.0
For MTR fuel elements described in 5(b)(1)(iv) and limited in 5(b)(2)(iv)	0.0
For metallic fuel rods described in 5(b)(1)(v) and limited in 5(b)(2)(v) and (vi)	0.0
For TRIGA fuel elements (in poisoned TRIGA fuel baskets) described in 5(b)(1)(vi)(a) and limited in 5(b)(2)(vii)(a)	0.0
For TRIGA fuel elements (in nonpoisoned TRIGA fuel baskets) described in 5(b)(1)(vi)(b) and 5(b)(1)(vi)(c) and limited in 5(b)(2)(vii)(b) and 5(b)(2)(vii)(c), respectively	12.5
For mixed loads of TRIGA fuel elements described in 5(b)(1)(vi)(c) and limited in 5(b)(2)(vii)(c), and TRIGA fuel cluster rods described in 5(b)(1)(vii)(b) and limited in 5(b)(2)(viii)(b)	12.5
For TRIGA fuel cluster rods described in 5(b)(1)(vii) and limited in 5(b)(2)(viii)	0.0
For high burnup PWR rods described in 5(b)(1)(viii) and limited in 5(b)(2)(ix)	0.0
For high burnup BWR rods described in 5(b)(1)(ix) and limited in 5(b)(2)(x)	0.0
For DIDO fuel elements described in 5(b)(1)(x) and limited in 5(b)(2)(xi)	12.5
For General Atomic Irradiated Fuel Material (GA IFM) described in 5(b)(1)(xi) and limited in 5(b)(2)(xii)	0.0
For TPBARS and segmented TPBARS described in 5(b)(1)(xii) and 5(b)(1)(xv) and limited in 5(b)(2)(xiii) and 5(b)(2)(xvi)	0.0
For intact (uncanned) PULSTAR fuel described in 5(b)(1)(xiii) and limited in 5(b)(2)(xiv)	0.0

5(c) Criticality Safety Index (CSI)

For (canned) PULSTAR fuel described in 5(b)(1)(xiii) and limited in 5(b)(2)(xiv) – for a package with any number of PULSTAR cans	33.4
For ANSTO fuel described in 5(b)(1)(xiv) and limited in 5(b)(2)(xv)	0.0
For solid irradiated hardware described in 5(b)(1)(xvi) and limited in 5(b)(2)(xvii)	0.0
For PWR MOX rods described in 5.(b)(1)(xvii) and limited by 5(b)(2)(xviii)	0.0
For a mixed fuel load of DIDO and ANSTO fuel elements described in 5(b)(1)(x) and 5(b)(1)(xiv) and limited by 5(b)(2)(xi)(b) and 5(b)(2)(xv)(b)	0.0
For (canned) SLOWPOKE fuel described in 5(b)(1)(xviii) and limited by 5(b)(2)(xix)	0.0
For NRU/NRX fuel described in 5.(b)(1)(xix) and limited in 5.(b)(2)(xx)	100.0
For HEUNL described in 5.(b)(1)(xx) and limited in 5.(b)(2)(xxi)	0.0

6. Known or suspected damaged fuel assemblies (rods) or elements, and fuel with cladding defects greater than pin holes and hairline cracks are not authorized, except as described in Items 5.(b)(1)(x); 5.(b)(1)(xiv); 5.(b)(1)(xviii); 5.(b)(2)(iv)(d); 5.(b)(2)(vi); 5.(b)(2)(vii)(a); 5.(b)(2)(vii)(b); 5.(b)(2)(viii); 5.(b)(2)(ix); 5.(b)(2)(x); 5.(b)(2)(xi); 5.(b)(2)(xiv); 5.(b)(2)(xv); and 5.(b)(2)(xix).

7. The cask must be dry (no free water) when delivered to a carrier for transport.

8. Bolt torque: The cask lids bolts must be torqued to 260 +/- 20 ft-lbs. The bolts used to secure the alternate vent and drain port covers must be torqued to 100 +/- 10 inch-lbs. The bolts used to secure the Alternate B port covers must be torqued to 285 +/- 15 inch-lbs.

9. Prior to each shipment, the package must be leak tested to 1 x 10^{-3} std cm^3/sec, except that replaced seals must be leak tested to 2.0 x 10^{-7} std cm^3/sec (He). Prior to first use, and at least once within the 12-month period prior to each subsequent use, the package must be leak tested to 2.0 x 10^{-7} std cm^3/sec (He).

10. In addition to the requirements of Subpart G of 10 CFR Part 71:

(a) The metallic O-ring lid seal must be replaced prior to each shipment; and

(b) Each package must meet the Acceptance Tests and Maintenance Program of Chapter 8 of the application; and

10. (continued)

(c) The package shall be prepared for shipment and operated in accordance with the Package Operations of Chapter 7 of the application. If the cask is loaded under water or water is introduced into the cask cavity, the cask must be vacuum dried as described in Chapter 7 of the application. The cask cavity must be backfilled with 1.0 atm of helium when shipping PWR or BWR assemblies, individual PWR and BWR rods, or TPBAR contents.

11. When shipping PWR, BWR, PWR MOX, MTR, DIDO assemblies, TRIGA fuel elements, TRIGA fuel cluster rods, high burnup PWR or BWR rods, GA IFM, PULSTAR fuel elements, spiral fuel assemblies, and MOATA plate bundles, the neutron shield tank must be filled with a mixture of water and ethylene glycol which will not freeze or precipitate in a temperature range from -40 °F to 250 °F. The water and ethylene glycol mixture must contain at least 1% boron by weight.

12. A personnel barrier must be used when shipping PWR or BWR assemblies. Shipments of MTR, DIDO fuel assemblies, TRIGA fuel elements, TRIGA fuel cluster rods, high burnup PWR or BWR rods, PWR MOX rods, TPBAR contents, PULSTAR fuel elements, spiral fuel assemblies, MOATA plate bundles, or irradiated hardware must use the ISO container or a personnel barrier.

13. Packages used to ship metallic fuel rods may be shipped in a closed shipping container provided that the closed container, the cask tie-down and support system and transport vehicle (trailer) meet the applicable requirements of the Department of Transportation. When the cask is shipped in a closed shipping container, the center of gravity of the combined cask, closed shipping container and trailer must not exceed 75 inches.

14. For shipment of TPBAR contents:

(a) Prior to first use for shipment of TPBAR contents, each packaging must be hydrostatic pressure tested to 450 +5/-0 psig, as described in Section 8.1.2 of the application;

(b) The package must be marked with Package Identification Number USA/9225/B(M)-96;

(c) The package must be configured as shown in NAC International Drawing No. 315-40-128, Rev. 4 (Sheets 1-2), for the applicable TPBAR contents; and

(d) Prior to each shipment, after loading, each cask containment seal must be tested to show no leakage greater than 2×10^{-7} std-cm^3/s (helium).

15. For shipment of PULSTAR fuel:

(a) Intact fuel elements may be configured as PULSTAR fuel assemblies, may be placed into a TRIGA fuel rod insert (a 4 x 4 rod holder), or may be loaded into PULSTAR fuel cans. Intact PULSTAR fuel assemblies and PULSTAR fuel elements in a TRIGA fuel rod insert may be loaded in any module of the 28 MTR basket assembly. PULSTAR fuel cans may only be loaded into the top or base module of the 28 MTR basket assembly.

15. (continued)

(b) Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies must be loaded into PULSTAR cans. Damaged PULSTAR fuel, including fuel debris, pellets or pieces, may be placed in an encapsulating rod prior to loading into a PULSTAR fuel can. PULSTAR fuel cans may only be loaded into the top or base module of the 28 MTR basket assembly.

(c) Loading of modules with mixed PULSTAR payload configuration is allowed.

16. For shipment of non-fissile contents, with fissile content in the package not exceeding Type A quantity, and qualifying as a fissile exempt quantity under 10 CFR 71.15, the Model No. NAC-LWT shall be designated as Type B(U)F-96, with package identification number USA/9225/B(U)-96.

17. Transport by air is not authorized.

18. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

19. Revision 55, 57 and 58 of this certificate may be used until December TBD, 2013, February TBD, 2014 and December TBD, 2014, respectively.

20. Expiration Date: February 28, 2015.

REFERENCES

NAC International, Inc., application dated June 18, 2010.

NAC International, Inc., supplements dated February 3, March 2, May 24, October 26, December 5 and December 28, 2012; January 24, February 14, and March TBD, 2013.

FOR THE U. S. NUCLEAR REGULATORY COMMISSION

Michael D. Waters, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Date: August 1, 2013

Enclosure 6

SAR Page Changes and LOEP

No. 9225 for NAC-LWT Cask

NAC-LWT SAR, Revision LWT-13B

HEUNL Amendment

February 2013
Revision LWT-13B

NAC-LWT

Legal Weight Truck Cask System

SAFETY ANALYSIS REPORT

NON-PROPRIETARY VERSION

Docket No. 71-9225

NAC
INTERNATIONAL

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1.1 Introduction

The NAC-LWT spent-fuel shipping cask has been developed by NAC International (NAC) as a safe means of transporting radioactive materials authorized as approved contents. The cask design is optimized for legal weight over the road transport, with a gross weight of less than 80,000 pounds. The cask provides maximum safety during the loading, transport, and unloading operations required for spent-fuel shipment. The NAC-LWT cask assembly is composed of a package that provides a containment vessel that prevents the release of radioactive material. The actual containment boundary provided by the package consists of a 4.0-inch thick bottom plate, a 0.75-inch thick, 13.375-inch inner diameter shell, an upper ring forging, and an 11.3-inch thick closure lid. The cask lid closure is accomplished using twelve, 1-inch diameter bolts. The cask has an outer shell, 1.20 inches thick, to protect the containment shell and also to enclose the 5.75-inch thick lead gamma shield. Neutron shielding is provided by a 5.0-inch thick neutron shield tank with a 0.24-inch (6mm) thick outer wall, containing a water/ethylene glycol mixture and 1.0 minimum weight percent (wt %) boron (58 wt % ethylene glycol; 39 wt % demineralized water; 3 wt % potassium tetraborate [$K_2B_4O_7$]). The neutron shield tank system includes an expansion tank to permit the expansion and contraction of the shield tank liquid without compromising the shielding or overstressing the shield tank structure. Aluminum honeycomb impact limiters are attached to each end of the cask to absorb kinetic energy developed during a cask drop, and limit the consequences of normal operations and hypothetical accident events.

The NAC-LWT is a legal weight truck cask designed to transport the following contents:

- 1 PWR assembly;
- up to 2 BWR assemblies;
- up to 15 sound metallic fuel rods;
- up to 42 MTR fuel elements;
- up to 42 DIDO fuel assemblies;
- up to 25 high burnup PWR fuel rods (including up to 14 rods classified as damaged)[1];
- up to 25 high burnup BWR fuel rods (including up to 14 rods classified as damaged)[1];
- up to 16 PWR MOX fuel rods (or a combination of 16 PWR MOX and UO_2 PWR rods) and up to 9 BPRs
- up to 9 damaged metallic fuel rods;
- up to 3 severely damaged metallic fuel rods in filters;
- up to 140 TRIGA intact or damaged fuel elements/fuel debris ("TRIGA" is a Trademark of General Atomics);
- up to 560 TRIGA intact or damaged fuel cluster rods/fuel debris;
- 2 GA IFM packages;
- up to 300 TPBARs (of which two can be prefailed) in a consolidation canister;

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[1] PWR and BWR fuel rods may be transported in either a fuel assembly lattice (skeleton) or in a fuel rod insert. The fuel rod insert may contain PWR instrument/guide tubes and BWR water/inert rods in addition to the fuel rods.

- up to 25 TPBARs (of which two can be prefailed) in a rod holder;
- up to 55 TPBARs segmented during post-irradiation examination (PIE), including segmentation debris;
- up to 700 PULSTAR fuel elements (intact or damaged);
- up to 42 spiral fuel assemblies;
- up to 42 MOATA plate bundles;
- 4 HEUNL containers (to fill capacity or empty; no partially filled); or
- up to 4,000 lbs of solid, irradiated and contaminated hardware, which may include fissile material less than a Type A quantity and meeting the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c). Total allowed mass includes the weight of spacers, shoring and dunnage.

PWR or BWR fuel rods may be placed in a fuel rod insert (also referred to as a rod holder) or in a fuel assembly lattice. The fuel rod holder is composed of a 4×4 or a 5×5 rod array. An alternate 5×5 rod holder is designed to contain an oversize nonfuel-bearing component (e.g., CE guide tube or BWR water rod). The alternative configuration reduces fuel-bearing capacity to a maximum of 21 fuel rods. The lattice may be irradiated or unirradiated. Up to 14 of the fuel rods may be classified as damaged. Damaged fuel rods must be placed in a rod holder. Damaged fuel rods or rod sections may be encapsulated to facilitate handling prior to placement in the rod holder. PWR rods may include Integral Fuel Burnable Absorber (IFBA) rods.

PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods) are required to be loaded in a screened or free flow PWR/BWR Rod Transport Canister with a 5×5 insert. PWR MOX/UO_2 rods may include Integral Fuel Burnable Absorber (IFBA) rods.

Damaged TRIGA fuel elements, cluster rods and fuel debris are required to be loaded in a sealed damaged fuel canister (DFC).

PULSTAR fuel elements may be configured as intact fuel assemblies, may be placed into a fuel rod insert, i.e., a 4×4 rod holder (intact elements only), or may be loaded into one of two can designs, designated as the PULSTAR screened fuel can or the PULSTAR failed fuel can. Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies must be loaded into cans. PULSTAR fuel cans may only be loaded into the top or base module of the 28 MTR basket assembly. Intact PULSTAR fuel assemblies and intact PULSTAR fuel elements in a TRIGA fuel rod insert may be loaded in any basket module.

Four HEUNL containers may be loaded directly into the NAC-LWT cask cavity. Containers must be at the fill capacity or empty. Partially filled HEUNL containers are not authorized for packaging. Fill capacity is defined as the point when material reaches the vent port during fill operations. Solution may be diluted with a similar acid solution to achieve container fill capacity.

seals. For all other contents, the leaktight capable (i.e., no credible leakage) alternate port covers incorporating Viton O-ring seals can be used. The transport arrangement drawings for approved contents are presented in Section 1.4.

An alternative drain tube, including a drain tube alignment ring, is required to be installed and utilized when loading and transporting modular fuel baskets (i.e., not full length) and canisters.

The impact limiters and the personnel barrier are designed to be removed and installed without the aid of supplemental lifting gear or fixtures. All approved content may be transported in an International Shipping Organization (ISO) container, except for PWR and BWR fuel assemblies. All operational features are readily apparent from the drawings provided in Section 1.4. Operational procedures are delineated in Chapter 7.

1.2.3 Contents of Packaging

The NAC-LWT cask is analyzed, as presented in this SAR, for the transport of the contents listed in Table 1.1-1 and Section 1.1.

Shipments in the NAC-LWT package shall not exceed the following limits:

1. The maximum contents weight shall not exceed 4,000 pounds.
2. The limits specified in Table 1.2-1 through Table 1.2-13 for the fuel and other radioactive contents shall not be exceeded.
3. Any number of casks may be shipped at one time, one cask per tractor/trailer vehicle.
4. The maximum decay heat shall not exceed the following: 2.5 kW for PWR fuel assemblies; 2.2 kW for BWR fuel assemblies; 2.3 kW for 25 high burnup PWR fuel rods; 2.1 kW for 25 high burnup BWR fuel rods; 2.3 kW for 16 PWR MOX/UO_2 fuel rods; 1.26 kW for MTR fuel; 1.05 kW for DIDO fuel assemblies with top spacer and 0.756 kW without top spacer; 1.05 kW for TRIGA fuel elements or fuel cluster rods; 13.05 W for GA IFM packages; 0.693 kW for 300 TPBARs; 0.127 kW for TPBAR segments; 0.058 kW for 25 TPBARs; 0.84 kW for the PULSTAR fuel contents; 0.659 kW for spiral fuel assemblies (0.109 kW per basket); 0.126 kW for MOATA plate bundles (21 W per basket); 12.88 W for HEUNL; and 1.26 kW for solid, nonfissile, irradiated hardware.
5. Radiation levels shall meet the requirements delineated in 10 CFR 71.47 or 49 CFR 173.441. The neutron shield tank may be drained for shipment of metallic fuel rods.
6. Surface contamination levels shall meet the requirements of 10 CFR 71.87(i) or 49 CFR 173.443.
7. Damaged TRIGA fuel elements and fuel debris (up to two equivalent elements) will be shipped in a sealed damaged fuel canister.
8. Damaged TRIGA cluster rod and fuel debris will be transported in a sealed damaged fuel canister (maximum of up to six equivalent fuel cluster rods).
9. MTR fuel elements may consist of any combination of intact or damaged highly enriched uranium (HEU), medium enriched uranium (MEU) or low enriched uranium (LEU) fuel elements that are enveloped by the parameters listed in Table 1.2-4 as supported by

information presented in Table 5.1.1-2, Table 6.4.3-21, Table 6.4.3-22, Table 6.4.3-25 and Table 6.4.3-28. MTR fuel elements will be transported in a leaktight configuration NAC-LWT cask.

10. High burnup PWR fuel rods will be shipped in either a sealed, free flow or screened can.
11. High burnup BWR fuel rods will be shipped in either a sealed, free flow or screened can.
12. Up to 25 high burnup PWR or BWR fuel rods in a fuel assembly lattice or rod holder. Up to 14 of the fuel rods in a rod holder may be classified as damaged. Damaged fuel rods or rod sections may be placed into fuel rod capsules prior to placing them in the fuel rod holder. Typical failed fuel rod capsule configuration is shown in Figure 1.2-11.
13. Production TPBARs will either be shipped in an open top consolidation canister as shown in Figure 1.2.3-10 and assembled in the cask as shown in Figure 1.2.3-12, or shipped in a PWR/BWR Rod Transport Canister in accordance with License Drawing No. 315-40-104.
14. Intact PULSTAR fuel elements may be loaded into a fuel rod insert or the PULSTAR screened or failed fuel can.
15. Damaged PULSTAR fuel elements and nonfuel components of PULSTAR fuel assemblies shall be loaded into either a PULSTAR failed fuel or screened fuel can, and placed into the top or base module of the 28 MTR fuel basket. Damaged fuel, including fuel debris, may be placed in an encapsulating rod prior to loading in a PULSTAR can.
16. Any combination of spiral fuel assemblies or MOATA plate bundles, each loaded into separate ANSTO basket modules containing up to a total of 42 assemblies/bundles.
17. Segmented TPBARs will be shipped in a sealed, dry Waste Container as shown in Figure 1.2.3-16 and assembled in the cask as shown in Figure 1.2.3-17.
18. Solid, irradiated and contaminated hardware containing less than a Type A quantity of fissile material and meeting the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c), loaded directly into the cask or contained in a secondary container or basket. The irradiated hardware spacer will be installed to limit the axial movement of the hardware above the lead shielded region of the cask body. As needed, additional secondary containers, dunnage and shoring may be used to limit the movement of the contents during normal and accident conditions of transport.
19. PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods) are required to be loaded in a screened or free flow PWR/BWR Rod Transport Canister provided with a 5 × 5 insert.
20. Any combination of up to 7 degraded clad DIDO, spiral or MOATA plate elements/ bundles loaded into an aluminum screened DFC as shown Figure 1.2.3-18 placed in an ANSTO top basket module, with remainder of either ANSTO basket modules containing MOATA plate bundles or spiral fuel elements or ANSTO-DIDO combination basket containing DIDO elements. Degraded aluminum-clad DIDO, spiral or MOATA plate elements/bundles will be transported in a leaktight configuration NAC-LWT cask.
21. Four HEUNL containers. Containers shall be either at fill capacity with HEUNL material or empty. Partially filled containers may not be packaged. Solution may be diluted with a similar acid solution to achieve container fill capacity.

plates. Two thick (0.635 cm) aluminum nonfuel side plates support the fuel plate stack from two sides, making a possible total of 16 plates per bundle. At each axial end, the plates in the stack are connected by a pin. Spacing between plates is maintained by disk spacers placed onto the top and bottom pins between each fuel plate and the aluminum side plates. A sketch of a typical MOATA plate bundle is provided in Figure 1.2.3-15.

1.2.3.10 Solid, Irradiated and Contaminated Hardware

The design basis characteristics of the solid, irradiated and contaminated hardware are provided in Table 1.2.3-13. As described in the content definition, the solid, irradiated and contaminated hardware may contain small quantities of fissile materials. Fissile materials in the irradiated hardware contents are acceptable if the quantity of fissile material does not exceed a Type A quantity and does not exceed the exemptions of 10 CFR 71.15, paragraphs (a), (b) and (c).

The irradiated hardware may be directly loaded into the NAC-LWT cask cavity, or may be contained in a secondary container or basket. As needed, appropriate component spacers, dunnage and shoring may be used to limit the movement of the contents during normal and accident conditions of transport.

To ensure that the movement of the irradiated hardware contents above the lead shielded length of the NAC-LWT cask body (i.e., the approximately upper 6.25 inches of the cavity length) is precluded, an Irradiated Hardware Lid Spacer as shown on Drawing No. 315-40-145 shall be installed for all irradiated hardware content configurations. The total installed height of the spacer is 6.5 inches. Therefore, the available cavity length for the irradiated hardware is approximately 171 inches. The NAC-LWT cask shall be assembled for transport as shown on NAC Drawing No. 315-40-01 with the irradiated hardware spacer installed on the lid.

A comparative shielding evaluation for a conservatively selected irradiated hardware transport configuration (i.e., a single line source with no self-shielding) or consideration of the additional shielding provided by additional spacers, dunnage, inserts or secondary containers is presented in Chapter 5. The evaluations show that the regulatory dose rate requirements per 10 CFR 71.47 for normal conditions of transport, or 10 CFR 71.51(b) under hypothetical accident conditions, are not exceeded.

1.2.3.11 PWR MOX Fuel Rods

The NAC-LWT cask is analyzed and evaluated for the transport of upto 16 PWR MOX fuel rods (or a combination of up to 16 PWR MOX and UO_2 fuel rods) loaded into a 5 × 5 insert placed in a screened or free flow PWR/BWR Rod Transport Canister. The authorized characteristics of the evaluated PWR MOX fuel rods are provided in Table 1.2-4. For mixed PWR MOX and UO_2 PWR fuel rod combinations, the UO_2 PWR fuel rods may have the identical heat load, burnup and cool time characteristics as the PWR MOX fuel rods.

In addition to the 16 PWR MOX fuel rods (or a combination of PWR MOX and UO_2 PWR fuel rods), up to 9 burnable poison rods (BPRs) may be loaded in the remaining openings in the 5 × 5 insert in the PWR/BWR Rod Transport Canister.

1.2.3.12 HEUNL Containers

HEUNL material packaged in HEUNL containers may be directly loaded into the NAC-LWT cavity. Four containers must be packaged in the NAC-LWT for transport. The containers must be at fill capacity or empty. Partially filled containers are not allowed for transport. Solution may be diluted with a similar acid solution to achieve container fill capacity. Fill capacity is defined as the point when material reaches the vent port during fill operations. A sketch of the HEUNL container is provided in Figure 1.2.3-19. The container design is presented in NAC drawing 315-40-181.

[redacted]

HEUNL material consists of a solution of uranyl nitrate, various other nitrates (primarily aluminum nitrate), and water. The solution may contain uranyl nitrates with up to 7.2 g/L ^{235}U. Key physical, radiation protection, and thermal characteristics of the HEUNL material are provided in Table 1.2.3-14.

Table 1.2.3-14 HEUNL Characteristics

Parameter	Value
Maximum HEUNL payload per Container	64.3 L (17.0 gal)
Maximum Cask Heat Load	12.88 W
Maximum Per Container Heat Load	3.22 W
Maximum HEUNL Heat Load	0.05 W/L
Maximum Curie Content (gamma emitters)[1]	9.0 Ci/L
Maximum ^{235}U content[2]	7.2 g ^{235}U/L

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[1] Maximum Curie content defined by source term and shielding evaluations.

[2] Maximum U content defined by criticality evaluation.

Table of Contents (continued)

Table of Contents (continued)

2.2 Weights and Centers of Gravity

2.2.1 Major Component Statistics

The weights of the major components of the NAC-LWT cask and their respective centers of gravity are presented in Table 2.2.1-1. The axial location of the center of gravity is measured from the bottom surface of the cask body. The center of gravity is always on the longitudinal centerline of the cask because the cask is essentially axisymmetric about that axis. The center of gravity location of the fuel is representative of typical fuel configurations.

The weights and centers of gravity of the cask package in eight different shipping configurations are presented in Table 2.2.1-2. In each case, the center of gravity is measured from the bottom surface of the cask body. The term "loaded" refers to the presence of fuel or other radioactive materials in the cask cavity; the term "empty" implies the absence of any fuel or other radioactive materials in the cask cavity. However, the fuel basket does remain in the cask cavity for the "empty" configuration. The weight of a lifting yoke is not included in the tabulated package weights.

All of the values tabulated in Table 2.2.1-1 and Table 2.2.1-2 are calculated to the nearest pound to obtain an accurate cask weight and center of gravity. The cask package weight and center of gravity used in the analyses of this report are the design values - 52,000 pounds and 98.93 inches. A design value of 4,000 pounds is conservatively used for the total weight of the cask contents (including the appropriate basket).

Table 2.2.1-1 Weights of the NAC-LWT Cask Major Components

Component	Weight (pounds)	Axial Center of Gravity Location (inches)
Cask Body	39,906	96.46
Closure Lid and Bolts	941	195.11
Impact Limiters		
Top	1,535	202.98
Bottom	1,320	-3.18
Shield Tank Fluid	3,506	96.26
PWR Fuel Basket and Spacer	874	100.98
PWR High Burnup Rod Payload	1,620	95.33
PWR Fuel Payload (Maximum)	3,126	96.63
BWR Fuel Basket	1,124	97.88
BWR Fuel Payload	1,500	97.88
Metallic Fuel Basket	128	96.40
Metallic Fuel Payload	2,080	96.40
MTR Four Unit Basket	982	96.20
MTR Four Unit Fuel Payload	840[1]	96.20
MTR Four Unit PULSTAR Fuel Payload	2,240[2]	96.20
MTR Five Unit Basket	1,015	96.20
MTR Five Unit Fuel Payload	1,050[1]	96.20
MTR Six Unit Basket	1,002	96.20
MTR Six Unit Fuel Payload	1,260[1]	96.20
GA IFM Basket and Spacer	818	98.06
GA IFM Fuel Payload	148	167.34
TPBAR Basket and Spacer	675	110.40
TPBAR Payload	978[3]	96.00
ANSTO Basket	911	100.95
ANSTO Payload	756	100.95
TPBAR Basket	575	97.43
TPBAR with Rod Transport Canister Payload	1,326[4]	102.26
HEUNL Container & Spacer[5]	1,316	104
HEUNL Payload	760	98

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[1] For conservatism, a design basis MTR fuel weight of 30 lbs/assy is used in the structural analysis. The maximum MTR element weight is 13.2 lbs for an intact element and 9.7 lbs for the cut elements in the 42-element configuration.

[2] For conservatism, a bounding weight of 80 pounds is considered for each of the 28 fuel cells for PULSTAR fuel

[3] TPBAR payload represents the combined weight of the TPBAR and consolidation canister. A conservative 1,000 lb weight is applied in the structural analysis.

[4] TPBAR with Rod Transport Canister payload represents the combined weight of the 25 TPBARs, the PWR /BWR Rod Transport Canister and the PWR insert.

[5] Includes 4 HEUNL Containers, Container Guide and Container Spacer.

Table 2.2.1-2 Weights and Center of Gravity Locations for the NAC-LWT Cask Shipping Configurations

Component	Weight (pounds)	Axial Center of Gravity Location (inches)
Package -Loaded for Shipment (PWR) Maximum Payload	51,208	98.96
Package – Loaded for Shipment PWR High Burnup Rods	49,702	99.0
Package - Empty for Shipment (PWR)	48,082	99.12
Package - Loaded for Shipment (BWR)	49,832	99.00
Package - Empty for Shipment (BWR)	48,332	99.07
Package - Loaded for Shipment* (Metallic Fuel)	45,910	98.88
Package - Empty for Shipment* (Metallic Fuel)	43,830	99.09
Package - Loaded for Shipment (PULSTAR Fuel, MTR Four Unit Basket)	50,430	99.1
Package - Loaded for Shipment (MTR Fuel, Four Unit Basket)	49,030	99.1
Package - Empty for Shipment (MTR Fuel, Four Unit Basket)	48,190	98.9
Package - Loaded for Shipment (MTR Fuel, Five Unit Basket)	49,273	99.1
Package - Empty for Shipment (MTR Fuel, Five Unit Basket)	48,223	98.9
Package - Loaded for Shipment (MTR Fuel, Six Unit Basket)	49,470	99.1
Package - Empty for Shipment (MTR Fuel, Six Unit Basket)	48,210	98.9
Package - Loaded for Shipment (GA IFM Fuel and Basket)	48,147	99.3
Package - Empty for Shipment (GA IFM Basket)	48,026	99.3
Package – Loaded for Shipment (TPBARs and Basket)	48,861	99.2
Package – Empty for Shipment (TPBAR Basket)	47, 883	99.2
Package - Loaded for Shipment (ANSTO Fuel and Basket)	48,875	99.2
Package - Empty for Shipment (ANSTO Basket)	48,119	99.1

* Neutron Shield Tank is empty.

Table 2.2.1-2 Weights and Center of Gravity Locations for the NAC-LWT Cask Shipping Configurations (cont'd)

Component	Weight (pounds)	Axial Center of Gravity Location (inches)
Package – Loaded for Shipment TPBARs in the PWR/BWR Rod Transport Canister	49,109	99.2
Package – Empty for Shipment (TPBAR Basket for PWR/BWR Rod Transport Canister)	47,783	99.1
Package – Empty for Shipment (HEUNL)	48,527	99.2
Package – Loaded for Shipment (HEUNL)	49,287	99.2
Package – Design for Shipment	52,000	98.93

2.6.12 Fuel Basket / Container Analysis

2.6.12.1 Discussion

To assure that the cask contents are retained in a subcritical and safe configuration, a fuel basket supports the contents both laterally and longitudinally. During normal transport, the cask may sustain a 1-foot free fall to either the side, corner or end drop orientations. Fuel basket designs examined under normal operations conditions are: the PWR basket (Section 2.6.12.2); the BWR basket (Section 2.6.12.4); the metallic fuel basket (Section 2.6.12.5); the MTR basket (Section 2.6.12.6); the TRIGA fuel basket (Section 2.6.12.7); the DIDO fuel basket (Section 2.6.12.8); the GA IFM basket (Section 2.6.12.9); the TPBAR basket and spacer (Section 2.6.12.10); ANSTO fuel basket (Section 2.6.12.11), and the HEUNL containers (Section 2.6.12.13). The transport configuration can also accommodate a combination of an ANSTO top basket module and five DIDO basket modules. Within the top ANSTO module of the ANSTO-DIDO combination basket assembly, a total of up to seven aluminum damaged fuel cans (DFCs) can be placed. The total additional weight of the seven DFCs is less than 35 pounds. The increased weight is bounded by the analysis weight of 1,770 lbs, per Section 2.6.12.11.2, which exceeds the calculated weight of the ANSTO baskets in Table 2.2.1-1 of 1,667 lbs (911 + 756 = 1,667) by 103 pounds. Table 2.2.1-1 confirms that the maximum weight of the four HEUNL containers is bounded by the design basis payload of 4,000 pounds. The analyses demonstrate that each of the basket designs is supported by the inner shell in bearing during a side drop, and that none of the basket designs will buckle during an end drop. The effects of a corner drop are bounded by the side and end drops.

2.6.12.2 PWR Basket Construction

The cylindrical basket body is fabricated from 6061-T6 aluminum alloy extrusions. An open, square, central core extends the length of the basket and provides lateral support for the cask contents. A 13.25-inch outside diameter, 0.125-inch thick aluminum tube that is 4.38 inches long, is bolted to the top of the basket body. This top tube protects the cask inner shell from damage during fuel loading operations and provides lifting points, which are used when the basket is removed from the cask. An aluminum spacer plate assembly is bolted to the bottom of the basket body. The spacer plate assembly supports the fuel basket and contents longitudinally, providing their movement within the cask. Additional spacer fixtures are either bolted to the cask lid or to the base of the fuel basket, if the cask contents do not fill the basket. The maximum spacer loads occur for the 30-foot drop hypothetical accident load conditions. The spacer analysis is presented in Section 2.7.7.8. A groove on the outside of the basket body is provided for the cask drain tube. The drain tube is connected to a fitting on the cask body, and is used to drain or fill the cask during cask loading or unloading operations.

For the shipment of up to 25 PWR or BWR rods, or up to 16 PWR MOX rods (or mixed MOX and UO_2 rods), a canister with insert will be utilized to position the fuel rod contents within the PWR basket. The canister for the fuel rods will be fabricated from Type 304 stainless steel (minimum thickness 0.12 inch) and will be designed to allow positive handling of the canister during loading and unloading operations. The size, shape, closure design and capacity of the canister will vary depending on the requirements of the shipping and/or receiving facilities. A spacer fabricated from stainless steel will be utilized, as required, to position the PWR/BWR rod canister longitudinally within the NAC-LWT cask cavity. A PWR insert fabricated from 6061-T651 aluminum is used to laterally position the rod canister within the PWR basket. The total weight of the fuel rods, canister and basket insert will be less than the maximum PWR fuel assembly payload weight of 1,650 pounds. Therefore, the up to 25 fuel rods content condition is bounded by the current PWR basket analyses.

2.6.12.3 PWR Basket Analysis

The minimum ambient temperature during normal transport, -40°F, combined with the maximum decay heat load produces an average inner wall temperature of 151°F. The 6061-T6 aluminum alloy expands approximately 1.5 times more per degree Fahrenheit than stainless steel. Assuming that both the cask and basket respond linearly, the maximum as-designed gap between the basket and the cavity, when the basket is centered in the cavity, is 0.094 in. Since aluminum expands faster than stainless steel, any increase in temperature will serve to decrease the basket-cavity gap. Since the gap is small, it is assumed that there is no relative motion between the basket and cask, and that the basket is in contact bearing on the inner shell during a side drop. The basket bearing loads are transmitted to the inner shell and cask structure.

2.6.12.3.1 Bearing Stress Calculation

The bearing stress is calculated using Case 6 (Roark, page 320), which models the cylindrical basket in a circular groove. The maximum compressive stress is calculated using:

$$S_{c_{max}} = 0.798 \left[\frac{\dfrac{P(D_1 - D_2)}{D_1 D_2}}{\dfrac{1 - \nu_1^2}{E_1} + \dfrac{1 - \nu_2^2}{E_2}} \right]^{0.5}$$

$$= 1570 \text{ psi}$$

where the material properties at 250°F are:

Transport Canister (66 lbs). Therefore, no further analysis is required for the 4×4 and 5×5 inserts.

2.6.12.13 HEUNL Container

[redacted]

There will be a total of 4 HEUNL containers in the LWT cask. A support spacer will be located at the bottom of the LWT cask between the bottom container and the bottom forging of the LWT cask. The HEUNL containers and the support ring are structurally evaluated with a combination of standard handbook formulas and finite element models.

The weight of each container is 320 lbs and the weight of the HEUNL fluid was calculated to be 175 lbs which gives a total of 495 lbs. For the structural analysis the fluid weight was conservatively assumed to be 180 lbs. This gives a total weight of 500 lbs total.

2.6.12.13.1 Finite Element Models

HEUNL Container FEA Model

The finite element model (FEA) was constructed of ANSYS SOLID45 3D elements and CONTAC52 gap elements. Both the HEUNL container and contained fluid were modeled. There are CONTAC52 elements between the outside surface of the fluid region and the inner surface of the container to model the compression only loading by the liquid. For the side drop case, CONTAC52 elements were added to the outer surface of the guide rails to determine the load distribution between the HEUNL container and the inner surface of the LWT cask. The HEUNL container FEA model is shown in the Figure 2.6.12-9 through Figure 2.6.12-11.

Figure 2.6.12-9 HEUNL Container – Outside View

[redacted]

Figure 2.6.12-10 HEUNL Container – Inside View

[redacted]

Figure 2.6.12-11 HEUNL Container – Gap Elements Shown

[redacted]

Support Ring Model

The support ring is a flat annular, machined ring. The support ring is constructed from SA-240, Type 304. An axisymmetric FEA model of the support ring was constructed for the bottom drop structural evaluation. Gap elements were placed at the bottom edge of the ring to account for possible lift-off of one edge. The support ring is not loaded significantly by the side drop or the top end drop. The FEA Model is shown in Figure 2.6.12-12. Vertical constraints were applied to the lower end of the gap elements and a pressure load was applied to the model top surface for the inertial load of the containers.

Figure 2.6.12-12 HEUNL Container Support Ring – Axisymmetric Model

[redacted]

2.6.12.13.2 HEUNL Container 1-Foot Drop Cases

The HEUNL container is evaluated for both end drops (top and bottom drops) and a side drop. An equivalent acceleration of 25 g is used to evaluate the 1-foot drops.

For each drop case the FEA model is utilized. The linearized stresses are checked at 14 section locations. These sections used are shown in Figure 2.6.12-13 and Figure 2.6.12-14.

Figure 2.6.12-13 HEUNL Container – Section Locations

[redacted]

Figure 2.6.12-14 HEUNL Container – Section Locations

[redacted]

Sections P6, P7 and P13 are not shown in the figures but are located at the center of the container shell half way between the bottom end cap and the top end cap.

The allowable stress S_m for SA-240, Type 304 at 200 °F is 20 ksi.

Design Pressure Case

As identified in Section 8.1.4.4 the canister is to be hydrostatically tested to 150 psig. This condition is treated as a normal condition, which bounds the maximum pressure of 100 psig expected during normal operational conditions identified in Section 4.5.6. A pressure case of 150 psig was evaluated. For this case a 30° sector of the 180° model was used and the liquid region of material was eliminated.

The maximum membrane stress intensity from the 14 section cuts was 3.53 ksi and the maximum membrane plus bending stress intensity was 5.04 ksi. For the Normal Conditions of Transport, the margin of safety is 4.67 for the membrane stress and 4.95 for the membrane plus bending stress.

1 Foot Side Drop

For the side drop each container rests against the inner shell of the LWT cask. The gap elements on the outside surface of the guide bars have two nodes. The outermost nodes are constrained in the radial, tangential and axial direction. This boundary condition represents the inner surface of the LWT cask as rigid, which is a conservative approach since this produces higher loads on the container guide rails.

For the side drop case an acceleration of 25 g is applied in the lateral (X) direction.

The maximum membrane stress intensity from the 14 section cuts was 2.19 ksi and the maximum membrane plus bending stress intensity was 3.98 ksi. For the Normal Conditions of Transport, the margin of safety is greater than 8.13 for the membrane stress and 6.54 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.6.12.13.3.

The bearing stress between the guide rail and the inner surface of the LWT cask was also computed. Assuming that the entire weight of the filled container is supported by one guide rail, the bearing stress is 0.342 ksi, which gives a margin of safety greater than 10. For additional details refer to item 1 in Section 2.6.12.13.3.

1 Foot Bottom End Drop

For the bottom end drop case an acceleration of 25 g is applied in the vertical (Z) direction. The lowest container rests on the spacer ring, which rests on the bottom forging of the LWT cask. The vertical acceleration accounts for the weight of the lowest container; however, the remaining 3 containers are stacked on the top of the lowest container. To account for the weight of the other three containers an equivalent pressure load is applied to the top of the FEA model for the bottom container.

The maximum membrane stress intensity from the 14 section cuts was 4.72 ksi and the maximum membrane plus bending stress intensity was 6.30 ksi. Comparing this to the allowable stress gives a margin of safety of 3.23 for the membrane stress and 3.76 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.6.12.13.3.

The bearing stress between the lowest container and the top surface of the support spacer was computed. The bearing stress is 5.42 ksi, which gives a margin of safety against the yield strength of 3.61. The bearing stress between the bottom of the support ring and the bottom of the LWT cask was also checked. This bearing stress was 6.15 ksi, which gives a margin of safety of 3.07. For additional details refer to item 1 in Section 2.6.12.13.3.

The container wall was also evaluated for potential buckling with a standard closed form solution. The calculated critical buckling stress calculated was 131 ksi. Compared to the calculated compressive stress in the container wall of 5.42 ksi, the margin of safety is greater than 10. For additional details refer to item 1 in Section 2.6.12.13.3.

The support ring FEA model was utilized to evaluate this case. The maximum membrane stress intensity calculated was 16.77 ksi and the maximum membrane plus bending stress intensity was 20.19 ksi. Comparing this to the allowable stress gives a margin of safety of 0.19 for the membrane stress and 0.49 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.6.12.13.3.

1 Foot Top End Drop

For the top end drop case an acceleration of 25 g is applied in the vertical (-Z) direction. The topmost container rests on the closure lid of the LWT cask. The vertical acceleration accounts for the weight of the lowest container; however, the remaining 3 containers are stacked on the top of the lowest container. To account for the weight of the other three containers, an equivalent pressure load is applied to the bottom of the FEA model of the top container.

The maximum membrane stress intensity from the 14 section cuts was 4.91 ksi and the maximum membrane plus bending stress intensity was 6.00 ksi. Comparing this to the allowable stress gives a margin of safety of 3.07 for the membrane stress and 4.00 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.6.12.13.3.

The bearing stress between the topmost container and the bottom surface of the LWT cask closure lid was also checked. The bearing stress is 1.41 ksi, which gives a margin of safety greater than 10. For additional details refer to item 1 in Section 2.6.12.13.3.

The container wall was evaluated for potential buckling with a standard closed form solution. The calculated critical buckling stress calculated was 131 ksi. The calculated compressive stress in the container wall is 5.42 ksi; therefore, the margin of safety is greater than 10. For additional details refer to item 1 in Section 2.6.12.13.3.

Pressure Case

The HEUNL containers are filled at atmospheric pressure. In accordance with Section 4.5.6, the normal operating pressure is 100 psi. Section 8.1.4.4 identifies the hydro-test pressure to be 150 psi. For 150 psi internal pressure, the maximum membrane stress was 3.53 ksi and the maximum membrane plus bending was 5.04 ksi. Conservatively using the allowable stresses for normal conditions, the margin of safety for membrane stress was 4.67 and the margin of safety for membrane plus bending stress was 4.95.

Thermal Stresses

Since the heat load for each HEUNL container is less than 5 Watts, there will not be any significant thermally induced stresses for the Normal Condition of Transport.

Extreme Cold Ambient Conditions (-40 °F)

[redacted]

[redacted]

Figure 2.6.12-15 HEUNL Container 10° Sector Model of HEUNL Liquid

[redacted]

[redacted]

Figure 2.6.12-16 HEUNL Container 10° Sector Model

[redacted]

[redacted]

[redacted]

[redacted]

2.6.12.13.3 HEUNL Structural Calculations

1. 65008500-2010 "Canister Structural Evaluations for HEUNL in the NAC-LWT"

2.6.12.14 Conclusion

Loads generated during normal operations conditions for each basket assembly design result in total equivalent stresses, which each basket body can adequately sustain. Analyses show that all basket-bearing stresses during a side drop are much less than the material yield strength. Column analyses demonstrate that each basket assembly is self-supporting during an end drop. The minimum Margin of Safety, for all basket designs, is +0.10 as reported in Section 2.6.12.7.4 for the TRIGA basket; +0.003 as shown in Table 2.6.12-2 for the DIDO basket; +0.10 as reported in Section 2.6.12.9.2 for the GA fuel basket; and +0.26 as reported in Section 2.6.12.11.1 for the ANSTO basket. The HEUNL container has a minimum margin of safety of +0.42 as reported in Section 2.6.12.13.2. Therefore, it can be concluded that all basket/container designs have sufficient structural integrity for adequate service during normal conditions of transport.

Figure 2.7.7-2 Internal Pressure Case – 30° Sector Model

[redacted]

2.7.7.15.2 HEUNL Container 30 Foot Drop Case

The HEUNL container is evaluated for both end drops (top and bottom drops) and a side drop. An equivalent acceleration of 61 g is used to evaluate the 30 foot drops.

For each drop case, the container and the support ring FEA models are utilized. The linearized stresses are checked at 14 section locations for the container model. The sections used were shown in Figures 2.6.12-13 and 2.6.12-14, previously.

The allowable stresses are based on either S_m, which is 20.0 ksi, or S_u, which is 66.2 ksi for SA 240, Type 304 at 300 °F. The allowable stress for membrane is either 2.4 S_m or 0.7 S_u, whichever is smaller, and the allowable stress for membrane + bending is either 3.6 S_m or 1.0 S_u, whichever is smaller. For SA-240, Type 304, the lower allowable stresses are 2.4 S_m and 3.6 S_m.

30 Foot Side Drop

For the side drop each container rests against the inner shell of the of the LWT cask. The gap elements on the outside surface of the guide bars have two nodes. The outermost nodes are constrained in the radial, tangential and axial direction. This boundary condition represents the inner surface of the LWT cask as rigid, which is a conservative approach since this produces higher loads on the container guide rails.

For the side drop case an acceleration of 61 g is applied in the lateral (X) direction.

The maximum membrane stress intensity from the 14 section cuts was 4.20 ksi and the maximum membrane plus bending stress intensity was 7.55 ksi. This gives a margin of safety greater than 10 for the membrane stress and greater than 10 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.7.7.15.3.

30 Foot Bottom End Drop

For the bottom end drop case, an acceleration of 61 g is applied in the vertical (Z) direction. The lowest container rests on the bottom forging of the LWT cask. The vertical acceleration accounts for the weight of the lowest container; however, the remaining 3 containers are stacked on the top of the lowest container. To account for the weight of the other three containers an equivalent pressure load is applied to the top of the FEA model of the bottom container.

The maximum membrane stress intensity from the 14 section cuts was 11.51 ksi and the maximum membrane plus bending stress intensity was 14.79 ksi. This gives a margin of safety of 3.03 for the membrane stress and 3.48 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.7.7.15.3.

The container wall was also evaluated for potential buckling with a standard closed form solution. The calculated critical buckling stress calculated was 119 ksi. Compared to the calculated compressive stress in the container wall of 13.22 ksi, the margin of safety is 8.00. For additional details refer to item 1 in Section 2.7.7.15.3.

The support ring FEA model was utilized to evaluate this case. The maximum membrane stress intensity calculated was 40.92 ksi and the maximum membrane plus bending stress intensity was 49.26 ksi. Comparing this to the allowable stress gives a margin of safety of 0.13 for the membrane stress and 0.34 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.7.7.15.3.

30 Foot Top End Drop

For the top end drop case an acceleration of 61 g is applied in the vertical (-Z) direction. The topmost container rests on the closure lid of the LWT cask. The vertical acceleration accounts for the weight of the lowest container; however, the remaining 3 containers are stacked on the top of the lowest container. To account for the weight of the other three containers, an equivalent pressure load is applied to the bottom of the FEA model of the top container. Again the total reaction load was checked to ensure that the weight of all 4 containers was accounted for.

The maximum membrane stress intensity from the 14 section cuts was 11.99 ksi and the maximum membrane plus bending stress intensity was 14.65 ksi. This gives a margin of safety of 2.86 for the membrane stress and 3.51 for the membrane plus bending stress. For additional details refer to item 1 in Section 2.7.7.15.3.

The container wall was evaluated for potential buckling with a standard closed form solution. The calculated critical buckling stress calculated was 119 ksi. The calculated compressive stress in the container wall is 13.22 ksi; therefore, the margin of safety is 8.00. For additional details refer to item 1 in Section 2.7.7.15.3.

Internal Pressure Case

[redacted]

Thermal Expansion

[redacted]

2.7.7.15.3 HEUNL Structural Calculations

1. 65008500-2010, "Canister Structural Evaluation for HEUNL in the NAC-LWT"

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$$\Delta T_a = (671°F - 387°F)\frac{0.1kW \times 1.15}{2.1kW \times 1.22} = 12.75°F$$

$$\Delta T_b = (228°F - 222°F)\frac{0.1kW}{0.69kW} = 0.87°F$$

$$\Delta T_{total} = \Delta T_a + \Delta T_b = 14°F$$

where:

ΔT_a: is the temperature difference between the maximum contents temperature and PWR insert for the TPBARs in the PWR/BWR Rod Transport Canister configuration.

ΔT_b: is the temperature difference across the TPBAR basket to the inner surface of the inner shell for the TPBARs in the PWR/BWR Rod Transport Canister configuration.

ΔT_{total}: is the temperature difference from the inner surface of the inner shell to the maximum contents temperature.

The maximum contents temperature for the TPBARs in the PWR/BWR Rod Transport Canister configuration is calculated as follows for the normal conditions of transport.

$$T_{max\ contents} = Tis_{max} + \Delta T_{total} = 222°F + 14°F = 236°F$$

where:

Tis_{max}: is the assumed maximum inner shell temperature for the TPBARs in the PWR/BWR Rod Transport Canister configuration

The maximum contents temperature for the NAC-LWT transport cask loaded with TPBAR fuel, the PWR/BWR Rod Transport Canisters, the PWR insert and the TPBAR basket is lower than the maximum temperature for the 300 TPBARs in the TPBAR basket analysis of Section 3.4.1.12 (236°F versus 290°F). Therefore, the component temperatures for the 25 TPBARs in the Rod Transport Canister configuration are bounded by the results of Section 3.4.1.12, which are summarized in Table 3.4-16.

3.4.1.18 Thermal Evaluation of HEUNL

Thermal analysis of the NAC-LWT with HEUNL containers is performed using the general purpose ANSYS computer code and a two-dimensional finite element model representing a 180-degree cross section of the LWT cask. The model represents the cask contents inside the cask inner shell. The NAC-LWT is supported in an ISO container with solar insolance applied on the surface of the ISO container, and the NAC-LWT is considered to be insulated from the environment (only for the normal conditions of transport steady state condition). The gas inside the ISO container is air. The ambient temperature is 100°F with solar insolance.

A 180-degree two-dimensional planar model, as shown in Figure 3.4-21, is generated due to the symmetry of the geometry and the heat load. [redacted] The HEUNL container is modeled with stainless steel properties. The gap between the LWT inner shell and the HEUNL container is air without radiation. The total heat load of 12.88 W for the whole cask is used and is distributed over the cavities of the four (4) containers. The heat generation rate applied to the liquid in the two-dimensional model is 0.05 W/liter (0.0028 Btu/hr-in3), based on the total heat load.

A constant temperature of 134°F is applied to the outer surface of the model, which corresponds to the maximum inner shell temperature. This maximum cask inner shell temperature is obtained using the two-dimensional ANSYS model for normal condition (Condition 1) from Section 3.4.1.3 after deleting all elements inside the cask inner shell. A heat flux computed based on a heat load of 12.88 W/cask, as follows, is applied to the inner surface of the cask inner shell of this two-dimensional model to obtain the maximum cask inner shell temperature of 134°F.

$$H\_flux = \frac{3.22 \times 3.413}{\pi \times 13.375 \times 30} = 0.0088\, Btu/(hr - in.^2)$$

where:
3.22 Watts is the heat load for a container;
13.375 inches is the ID of the LWT cask inner shell;
30 inches is conservatively used for the axial length for one container assembly.

The maximum temperature in the HEUNL model is computed to be 139°F. This confirms that for normal condition of transport, the HEUNL remains in the liquid state and that the maximum HEUNL container temperature is significantly lower than the allowable temperature of 800°F for stainless steel (Table 3.4-10). Maximum temperature of slide bars [redacted] of the HEUNL container is bounded by the liquid temperature of 139°F, which is lower than the allowable temperature of 392°F for PTEF. This allowable temperature is established based on "Safety in Handling and Use," by DuPont and "Teflon Offgas Studies," by Environmental Working Group. The heat load of the HEUNL (12.88 W) is bounded by the heat load of the MTR fuel (1.26 kW, Section 3.1). Therefore, the maximum temperatures of the cask components for the MTR contents (Condition 1, Table 3.4-6) bounds the maximum temperatures for the cask components for HEUNL.

definition, and ANSTO MOATA fuel is bounded by the generic MTR fuel definition. Minimum transport cool times are chosen for the analysis. None of the payloads generate significant quantities of actinide alpha decay gases, as plutonium generation is limited in the fuel elements modeled at 19% or greater ^{235}U enrichments. The negligible buildup of alpha decay gases makes the choice of cool time insignificant to the analysis results.

Fission product and actinide gas inventories in grams extracted from the SAS2H outputs are listed in Table 3.4-24. Fission gas inventories in grams are converted to inventories in moles using Avogadro's number and the atomic mass of each isotope. As illustrated in Table 3.4-25, the total molar quantity of fission gas does not vary significantly between various enrichment levels for a given fuel type. The MTR elements produce the bounding fission gas content. The majority of fission gases, ~85%, is comprised of Xenon isotopes. There is no significant quantity of helium or tritium.

3.4.4.8.2 Normal Condition Pressures

Using Dalton's Law of partial pressures, the NAC-LWT cask cavity pressure may be calculated by first determining the partial pressure of the released fission gases and adding it to the cask backfill gas. Gas available for release from the fuel elements depends on the fueled surface area exposed by clad-through damage.

Cask Backfill Gas

Based on the ideal gas law, the pressure of the cask backfill gas is simply the ratio of the backfill temperature at testing (assumed at standard temperature) to the operating condition temperature.

$$P_{\text{Cask Backfill}} = 14.7\ \text{psi} \times \frac{T_{\text{Operating Temperature}}}{T_{\text{Standard Conditions}}}$$

Partial pressures of the cask backfill at normal and accident conditions are 23.8 psi and 25.9 psi for ANSTO/DIDO and MTR payloads, respectively.

Fission Gas

The pressure of rod fission gas is calculated using release fraction (or surface area fraction assuming 100% release from the unclad fuel meat), the quantity of fission gas in the element, the cask cavity backfill temperature and the cask cavity gas temperature.

$$n = \text{Fission Gas Moles (Cask)} \times \text{Release Fraction}$$

$$P = \frac{\text{nRT}}{\text{V}}$$

For the MTR LEU fuel, a sample calculation based on a 50% surface area exposed with a 100% gas release from the exposed surface area is:

$$P_{\text{Fission Gas}} = = \frac{0.455\,\dfrac{\text{moles}}{\text{element}} \times 42\,\dfrac{\text{elements}}{\text{cask}} \times 50\% \times 0.08206\,\dfrac{\text{liters}-\text{atm}}{\text{k}-\text{mole}} \times 470.2\text{K}}{229.3\text{ liters}}$$

$$P_{\text{Fission Gas}} = 1.61\text{ atm} = 23.7\text{ psi}$$

Normal Pressure

Normal and accident pressures can now be generated at the various release/surface area fractions. Only LEU MTR and DIDO elements are summarized as they produce the maximum MTR and DIDO fission gas quantities and, therefore, pressures. Results are summarized in Table 3.4-26 as partial pressure of the fission gas and total system pressure in psia and psig. To meet a 50 psig system structural analysis limit, a maximum 80% of the MTR and 100% of the DIDO/ANSTO gases can be assumed to escape from the plates. As MTR plates with significant through-clad damage will have released a portion of their gas inventory prior to transport (i.e., during in-core use, storage and cask vacuum drying), system pressure is expected to remain below 50 psig when considering all fission gas released from the MTR plates.

Note that experimental data summarized in WSRC-TR-98-00317, October 1998, "Bases for Containment Analysis for Transportation of Aluminum–Based Spent Nuclear Fuel," Section 5.3.1, indicates no significant release of gases from exposed fuel material occurs at the temperature (200°C -300°C) of the NAC-LWT cask cavity and contents with aluminum-based fuel payload.

3.4.4.9 Maximum Internal Pressure for HEUNL Contents

3.4.4.9.1 Cask Containment

[redacted]

[redacted]

3.4.4.9.2 HEUNL Container

[redacted]

Empty containers may be present during transport. The container will contain air and be sealed by the quick disconnects and cover plate (same configuration as containers with solution). Applying ideal gas law to a 1 atm backfill at 68°F (standard room temperature), fill point yields a normal condition pressure of 2 psig.

3.4.5 Maximum Thermal Stresses

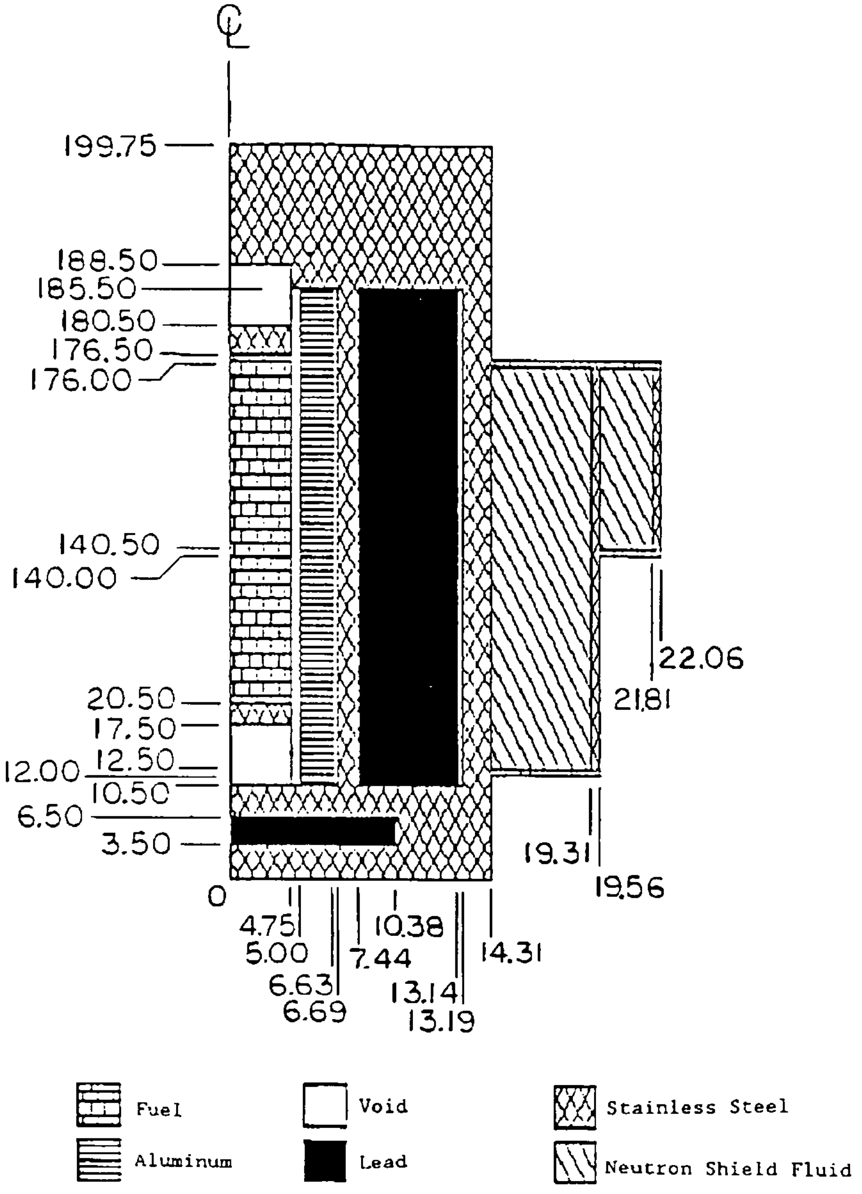
The conditions within the range of normal transport conditions and fabrication that result in the limiting combination of thermal gradient and isothermal stresses have been evaluated. The analyses are performed in Sections 2.5 through 2.7. The resulting isothermal temperature plots are presented in Section 2.10.3.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

Section 3.4 provides analyses of the NAC-LWT cask thermal performance for normal transport conditions. The analyses demonstrate that the NAC-LWT cask thermal performance meets the criteria of 10 CFR 71 for normal transport conditions.

The maximum fuel rod cladding temperature under normal transport conditions is 472°F. This is well below the temperatures that can cause fuel rod cladding deterioration. Components important to safety remain within their safe operating ranges (Section 3.3) during normal transport conditions. Thermally induced stresses (in combination with pressure and mechanical load stresses) are less than allowable stresses as shown in Section 2.6. Thus, the analyses of Section 3.4 demonstrate that the NAC-LWT cask fulfills the heat rejection criteria established in Section 3.1 for normal transport conditions.

Figure 3.4-1 HEATING5 Normal Transport Conditions Thermal Model



(Dimensions in inches)

configurations for the ANSTO-DIDO basket assembly. Therefore, for the fire accident condition, the same basis would confirm that the fuel and component temperatures for the fire accident conditions evaluated in Section 3.5.3.6 for DIDO fuel and Section 3.5.3.12 for ANSTO fuel types are bounding for the maximum fuel temperature in the conditions of the ANSTO-DIDO basket assembly.

3.5.3.15 Evaluation for TPBARs in the PWR/BWR Rod Transport Canister

Similar to Section 3.5.3.10, the maximum heat load of TPBARs in the Rod Transport Canister is bounded by the maximum heat load of the MTR fuel. Therefore, in the accident condition, the maximum temperatures of the cask components for the MTR contents will bound the maximum temperatures for the cask components for the TPBAR contents. It is conservative to use the results of the fire transient evaluated in Section 3.5.3.2 for the cask inner shell temperature. The maximum content temperature (T_{max}) for the TPBARs in a Rod Transport Canister for the accident conditions are determined by adding the temperature difference ($\Delta T_{component}$) between the cask inner shell and the maximum component temperature for normal conditions to the maximum accident cask inner shell temperature ($T_{inner\ shell}$) obtained from the MTR evaluation. The maximum component temperature is computed as follows.

Component	$\Delta T_{component}$[1] (°F)	$T_{inner\ shell}$[2] (°F)	T_{max} (°F)
TPBAR	14	334	348

[1] See Section 3.4.1.17
[2] See Table 3.5-2

The computed maximum contents temperature is less than for the TPBAR analysis of Section 3.5.3.10. Therefore, the component temperatures, namely, the aluminum basket and TPBARs, for the fire accident condition are bounded by the results of Section 3.5.3.10.

3.5.3.16 Evaluation of HEUNL

The heat load used for HEUNL (12.88 W) is significantly lower than the heat load of 1.26kW for the MTR fuel (Section 3.1). The same LWT cask is used for loading HEUNL and for loading MTR fuels. Therefore, it is conservative to use MTR fire accident case cask inner shell temperature increase for the HEUNL evaluation. The maximum inner shell temperature is 337°F for fire accident (Table 3.5-2, Condition 2) and the minimum inner shell temperature for the normal condition is 180°F (Table 3.4-6, Condition 2) for the MTR configuration. The bounding temperature increase of the inner shell due to fire accident is 157°F (337°F-180°F) during the fire and cool down stages, which corresponds to Condition 2 (cask transported via truck trailer and cavity gas is air).

To get a bounding temperature of HEUNL for the fire accident condition, it is conservative to add this temperature increase of 157°F to the maximum liquid temperature of 139°F for the normal condition (Section 3.4.1.18) since it neglects the thermal inertia of the entire contents inside the HEUNL cask. Therefore, the maximum liquid temperature for HEUNL is conservatively determined to be 296°F (139°F+157°F) for the fire accident condition. Maximum temperature of slide bars (made of PTEF) of the HEUNL container is bounded by the liquid temperature of 296°F, which is lower than the normal allowable temperature of 392°F for PTEF. This allowable temperature is established based on "Safety in Handling and Use," by DuPont, and "Teflon Offgas Studies," by Environmental Working Group. Maximum temperature of the HEUNL container is bounded by the liquid temperature of 296°F, which is lower than the normal allowable temperature of 800°F for stainless steel (Table 3.5-1); therefore, the HEUNL containers are determined to be acceptable for the fire accident.

3.5.4 Maximum Internal Pressure

3.5.4.1 Maximum Internal Pressure for Design Basis Fuel in Accident Conditions

The accident internal pressure is calculated assuming an accident with 100 percent fuel rod failure combined with the design basis fire described in 10 CFR 71. The fuel rod failure assumes 30 percent of the fission gas and 100 percent of the backfill gas escapes the ruptured fuel rods.

The internal pressure due to the 100 percent fuel rod rupture is calculated using the method described in Section 3.4.4. The total cask pressure of the cask backfill and failed fuel rods is calculated by a two step procedure. First, the pressures documented under normal conditions in Section 3.4.4 are adjusted to include the increased total free volume associated with 100% fuel rod failure. Then, the revised cask pressure at normal operating temperature is adjusted to accident condition temperatures.

Adjusting the partial pressure of the cask backfill:

$$P_{cask} = P_{initial}\left(\frac{V_{cask}}{V_{total}}\right)$$

where:

$P_{initial}$ = 25.8 psia (normal condition temperature adjusted cask backfill pressure)

V_{cask} = 5.196 ft^3 (147,134 cm^3) [Section 3.4.4]

$V_{\text{rod void}}$ = 8,123 cm^3 [Section 3.4.4]

V_{total} = 155,257 cm^3 ($V_{\text{cask}} + V_{\text{rod void}}$)

$$P_{\text{cask}} = 25.8\text{ psia}\left(\frac{147{,}134\text{cm}^3}{155{,}257\text{cm}^3}\right)$$

$$P_{\text{cask}} = 24.4\text{ psia}$$

Adjusting the partial pressure of the fuel rod backfill and fission gases:

$$P_{\text{fuel rods}} = P_{\text{initial}}\left(\frac{V_{\text{rod void}}}{V_{\text{total}}}\right)$$

where:

P_{initial} = 1,521.3 psia (fuel rod backfill pressure of 989.8 psia plus fission gas pressure of 0.30 x 1771.5 psia)

$V_{\text{rod void}}$ = 8,123 cm^3

V_{total} = 155,257 cm^3

$$P_{\text{fuelrods}} = 1{,}521.3\text{ psia}\left(\frac{8{,}123.28\text{cm}^3}{155{,}257\text{cm}^3}\right)$$

$$P_{\text{fuelrods}} = 79.6\text{ psia}$$

Summing the two partial pressures yields the total cask pressure at normal operating condition temperature:

$$P_{\text{Total}} = P_{\text{cask}} + P_{\text{fuelrods}}$$

$$P_{\text{Total}} = 24.4\text{ psia} + 79.6\text{ psia}$$

$$P_{\text{Total}} = 104.0\text{ psia}$$

The fuel cladding has the highest temperature of any barrier with which the gas comes in contact during a design basis fire. As shown in Section 3.5.3.1, the maximum average cavity gas temperature is 605°F during the fire accident condition. For conservatism, a temperature of 667°F is used in the calculation of the maximum accident condition internal pressure. Given that the internal volume of the NAC-LWT Cask remains constant during the fire, the resultant pressure is proportional to the temperature change according to the ideal gas law:

$$P_2 = P_1\left(\frac{T_2}{T_1}\right)$$

Thus, for the design basis fire:

$$P_{\text{fire}} = 104.0\ \text{psia}\left(\frac{1127^\circ \text{R}}{932^\circ \text{R}}\right)$$

$$P_{\text{fire}} = 125.8\ \text{psia}$$

3.5.4.2 High Burnup Fuel Rod Canister Maximum Internal Pressure

The high burnup fuel rod canister maximum internal pressure in the accident conditions is calculated assuming 100 percent fuel rod failure combined with the design basis fire maximum temperature. The fuel rod failure assumes release of 30 percent of the fission gas and 100 percent of the backfill gas.

The canister internal pressure is calculated using the method described in Section 3.4.4.2, with the BWR used as the bounding fuel type for the analysis. The total canister pressure is calculated in two steps. First, the pressures documented under normal conditions in Section 3.4.4.2 are adjusted to include the increased total free volume associated with 100 percent fuel rod failure. Then, the canister pressure is adjusted to account for the accident condition temperature.

The partial pressure of the canister volume is calculated by:

$$P_{\text{canister}} = P_{\text{initial}}\left(\frac{V_{\text{canister}}}{V_{\text{total}}}\right)$$

where:

P_{inital} = 29.3 psia (from earlier)

V_{canister} = 28.2 liters (from earlier)

V_{void} = 0.079 liters (from earlier)

V_{void} = $25 * V_{\text{void}} + V_{\text{canister}} = 30.2$ liters

V_{total} = 30.2 liters

Therefore, P_{canister} is equal to 27.4 psia. The partial pressure of the fuel rods is calculated by:

$$P_{\text{fuel rods}} = P_{\text{initial}}\left(\frac{V_{\text{fuel rods}}}{V_{\text{total}}}\right)$$

where:

P_{initial} = 1,425 psia (earlier from Section 3.4.4.2)

$V_{\text{fuel rods}} = 25 * V_{\text{void}}$

$V_{\text{fuel rods}} = \sim 1.97$ liters (at 100% of the total fuel rod volume)

$V_{\text{total}} = 30.2$ liters ($V_{\text{canister}} + (25 * V_{\text{void}})$)

then:

$$P_{\text{fuel rods}} = 1{,}425 \text{ psia}\left(\frac{1.97 \text{ liters}}{30.2 \text{ liters}}\right) = \sim 94 \text{ psia}$$

and

$$P_{\text{total}} = P_{\text{canister}} + P_{\text{fuel rods}} = 27.4 \text{ psia} + \sim 94 \text{ psia} = \sim 121 \text{ psia} (\sim 8.2 \text{ atm})$$

For the 100% fuel rod failure and the design basis fire accident temperature of 725°F, the pressure is calculated by multiplying the 100% rod failure pressure by the inverse ratio of the normal condition temperature (588.7 K) to the accident temperature (658.15 K). The pressure thus calculated is 135 psia (~9.2 atm)

3.5.4.3 25-Rod Maximum Internal Pressure-Cask Cavity

Using the same methodology used to calculate the cavity pressure in Section 3.5.4.2, the pressure from the 100% fuel rod failure and the design basis fire accident temperature of 725°F is calculated using the cask cavity free gas volume (89.32 liters from earlier). The resulting pressure in the cask cavity, assuming that the gases within the canister are released to the cask cavity, is 67 psia (~4.5 atm).

3.5.4.4 TPBAR Shipment Cask Cavity Internal Pressure-Accident Conditions

Employing the normal condition TPBAR result in Section 3.4.4.5 of 276 psig for the 300 production TPBAR content condition and adjusting system pressure to the average accident gas temperature of 358°F yields a maximum accident condition pressure of 322 psig. For a period of one year following the 90-day cooldown, the pressure for this content condition increases to 337 psig. As discussed in Section 3.4.4.5, these values bound those of the up to 25 TPBAR transport configuration within the 5×5 rod holder. The rod holder combination contains significantly lower releasable gas quantities at similar free volume.

Utilizing the same assumptions as presented in Section 3.4.4.5 and the post-accident thermal conditions discussed above, the pressure for the 55 segmented TPBARs in the waste container will be less than 75 psia and, therefore, bounded by the 300 TPBAR content condition.

3.5.4.5 Maximum Internal Pressure for PULSTAR Fuel Payload

Maximum internal pressures under accident conditions are calculated using the same methodology as that employed in Section 3.4.4.6. The accident condition temperature is set to 394°F, and 100 percent of the fuel rods are assumed to fail. The resulting calculated pressures are summarized as follows.

Description	Free Volume	Pressure		
	(liters)	(atm)	(psia)	(psig)
Cask Pressure -28 Intact Assemblies	217.0	2.3	34.0	19.3
Cask Pressure -14 Intact Assemblies and 14 Cans	233.0	2.4	35.4	20.7
Can Pressure - PULSTAR Failed Fuel Can	1.53	5.0	73.9	59.2

3.5.4.6 Maximum Internal Pressure for 16 PWR MOX/UO_2 Fuel Rods in a Rod Holder

Using the same methodology used to calculate the cavity pressure in Section 3.4.4.4, the pressure from the 100% fuel rod failure with 100% gas release and the design basis fire accident temperature of 725°F is calculated. The resulting pressure in the cask cavity is 65.3 psig (80.0 psia, 5.4 atm).

3.5.4.7 Maximum Internal Pressure for Aluminum-Based Fuels

The maximum normal condition 100% fission gas release MTR payload is evaluated for accident pressure. This payload bounds the remaining aluminum based fuel payloads. The 100% release normal condition pressure in Section 3.4.4.9 is simply increased by the ratio of accident (528K) to normal (470K) temperature.

$$P_{\text{Accident}} = P_{\text{Normal}} \times \frac{T_{\text{Accident}}}{T_{\text{Nomals}}} = 73.1\text{psia} \times \frac{528\text{K}}{470\text{K}} = 82.1\text{psia} = 67.4\text{psig}$$

As the DIDO accident temperature is higher than the MTR temperature, the DIDO value is used as the ratio basis. Maximum accident pressure for aluminum-based fuel is conservatively calculated to be 68 psig.

3.5.4.8 Maximum Internal Pressure for HEUNL Contents

3.5.4.8.1 Cask Containment

[redacted]

3.5.4.8.2 HEUNL Container

[redacted]

Empty containers may be present during transport. The container will contain air and be sealed by the quick disconnects and cover plate (same configuration as containers with solution). Applying ideal gas law to a 1 atm backfill at 68°F (standard room temperature) fill point yields a pressure of 6.4 psig at accident temperature (applying 296°F).

3.5.5 Maximum Thermal Stresses

The most severe thermal stress conditions that occur during the fire test and subsequent cooldown have been evaluated. For conservatism, an internal pressure of 168 psig is used, in the analysis that is performed in Section 2.7.3. The temperatures corresponding to the maximum thermal stresses are reported in Table 3.5-1.

3.5.6 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

The NAC-LWT cask thermal performance has been assessed for the hypothetical accident, as specified in 10 CFR 71. The O-rings and the lead gamma shields remain within their safe operating ranges. The cask does not suffer any adverse structural consequences as a result of the thermal considerations of the hypothetical accident. The NAC-LWT cask maintains containment and does not exceed the dose rate limits of 49 CFR 173 as a result of the hypothetical accident.

3.5.7 Assessment of the Effects of the Fission Gas Release in the Fire Accident Condition

During the fire, the release of the fission gas is expected to reduce the effective thermal conductivity of the gas in the cavity or inside the sealed canisters. To assess the reduction of the thermal conductivity, the helium conductivity is factored by the ratio of the conservative initial fill pressure of 565 psia (Section 3.4.4) for the PWR fuel assemblies and the end of life pressure (which contains the fill gas plus the fission gas release) of 1,521 psia (Section 3.5.4). This ratio is computed to be 0.37. A conservative ratio of 0.24 is applied to the conductivity of helium, assuming that all fission product gases have a conductivity of zero.

For the temperatures shown, which envelope the maximum temperatures of the cavity gas in the accident condition, the reduced helium properties are larger than the thermal conductivity of air.

This is bounding because, as shown in Table 4.2-2, the volume of fission product gas produced by the design basis PWR assembly is higher than that for any other fuel loading.

The data below (Krieth) reflects the comparison of the air conductivity and the factored helium conductivity.

Temperature (°F)	Air Conductivity (K_{air}) (Btu/hr-in-F)	Helium Conductivity (Btu/hr-in-F)	Factored Helium Conductivity (K_{He}) (Btu/hr-in-F)	Ratio K_{He}/K_{air}
300	0.00161	0.00883	0.00212	1.32
400	0.00177	0.00958	0.00230	1.30
500	0.00193	0.01017	0.00244	1.26
600	0.00208	0.01075	0.00258	1.24
700	0.00223	0.01113	0.00267	1.20
800	0.00238	0.01150	0.00276	1.16

The analyses performed for the contents employed air as the gas in the cavity and containers for the accident condition. This demonstrates that the evaluation of the accident condition using air bounds the "reduced helium properties" case.

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4 CONTAINMENT

4.1 Containment Boundary

The containment boundary for the NAC-LWT cask consists of the 0.75-inch thick inner shell, the 4.0-inch thick bottom end plate, the 11.25-inch thick lid, the upper ring forging and the vent and drain port covers. The inner shell is fabricated from Type XM-19 stainless steel and the other components are fabricated from Type 304 stainless steel. The quick-disconnect valves used for filling and draining the cask cavity are not considered to be part of containment and are closed by the port covers. There are two port cover designs: alternate and Alternate B. The alternate port cover is fabricated from SA-705, Grade 630, condition H1150 precipitation-hardened stainless steel. The Alternate B port cover is fabricated from XM-19 stainless steel and is designed to withstand a higher MNOP. The Alternate B port covers are required to be installed for the transport of TPBAR contents. The cask containment boundary is illustrated in Figure 4.1.1

The closure lid's metallic O-ring seal and the port cover's Viton® O-ring (alternate port cover) or metallic face seal (Alternate B port cover) are also part of the containment boundary. The sealing surfaces for O-rings and seals are machined in accordance with seal manufacturers' recommendations to a finish suitable to achieve reliable leaktight sealing of the containment.

4.1.1 Containment Penetrations

The only containment penetrations in the NAC-LWT cask cavity are the cask lid and the vent and drain ports.

4.1.2 Seals and Welds

4.1.2.1 Seals

The O-rings of the cask lid and the vent and drain port covers are the seals that provide the containment boundary for the radioactive contents of the NAC-LWT cask, as described in Section 4.1. Appendix 4.5.1 contains the military specification that prescribes the physical and chemical properties of the TFE O-rings. Appendix 4.5.2 is the manufacturer's technical bulletin for the metallic O-rings. Appendix 4.5.3 contains a description of the leakage testing performed using the Viton® O-rings on the alternate port cover design at temperatures exceeding the manufacturer's elevated temperature limit. Appendix 4.5.3 also contains the O-ring manufacturer's material report on the Viton® material. Appendix 4.5.9 contains the technical specification on the Alternate B port cover HELICOFLEX® metallic face seal.

Seal testing prior to cask acceptance from the manufacturer, during routine and annual maintenance, and following assembly prior to transportation includes the fabrication leakage rate test, the maintenance leakage rate test, and the preshipment leakage rate test. All containment O-ring tests are performed in accordance with the requirements of ANSI N14.5-1997.

4.1.2.1.1 Fabrication Leakage Rate Test

Upon completion of fabrication, the cask containment shall be leakage tested to a leaktight criteria of 1×10^{-7} ref.cm^3/sec, per ANSI N14.5-1997, as described in Section 8.1.3. The equivalent allowable helium leakage rate at reference conditions is 2×10^{-7} cm^3/sec (helium), with a minimum helium leak test sensitivity of 1×10^{-7} cm^3/sec (helium).

4.1.2.1.2 Fabrication Pressure Test

During acceptance testing, the cask containment boundary shall be hydrostatically tested using the pressure test described in Section 8.1.2. This test verifies the sealing integrity of the package with a hydrostatic test pressure of 209 psig.

As an additional post-fabrication test, prior to performing the first TPBAR shipment in a specific NAC-LWT cask, the hydrostatic test described in Section 8.1.2 shall be performed with the Alternate B port covers installed. The test pressure for the hydrostatic test shall be 450 psig, which is 150% MNOP for the TPBAR content conditions.

The hydrostatic tests are further described in Chapter 8.

4.1.2.1.3 Preshipment Leakage Rate Test

Prior to shipment of a loaded NAC-LWT cask, the containment seals of the closure lid and the vent and drain port covers shall be individually leakage tested. For the alternate port covers, a pressure drop test is performed by pressurizing the volume between the containment seal and the test seal. This preshipment leakage rate test assures that the port covers and seals are properly installed and that there is no leakage in excess of the minimum test sensitivity of 1×10^{-3} ref cm^3/s.

If the alternate port cover's Viton® containment O-ring is replaced, a maintenance leakage rate test is required to be performed per Section 8.1.3.

The closure lid and the Alternate B port cover both utilize metallic O-rings for the containment boundary seal. Metallic O-rings are designed for a single use and must be replaced prior to each loaded transport, if the component is removed. Following installation of the closure lid and Alternate B port covers, maintenance leakage rate tests are performed on each component in accordance with the helium leak test procedures in Section 8.1.3.

4.1.2.2 Welds

All containment vessel welds are full penetration bevel or groove welds to ensure structural and containment integrity.

4.1.3 Closure

Closure of the containment vessel is provided by the twelve 1-8 UNC closure lid bolts, each tightened to 260 ± 20 ft-lb of torque. The lid bolts are SA-453, Grade 660 high alloy steel bolting material. The lid bolts are preloaded so that the lid seals remain fully compressed for all load conditions. The structural adequacy of the lid bolts is documented in Sections 2.1.3.2.2, 2.6.7.6 and 2.10.9. The closure lid O-ring seals are specified on Drawing No 315-40-02 in Section 1.4. The O-ring seals and grooves are selected based on the manufacturer's specifications to satisfy the pressure and temperature conditions incurred by the NAC-LWT cask.

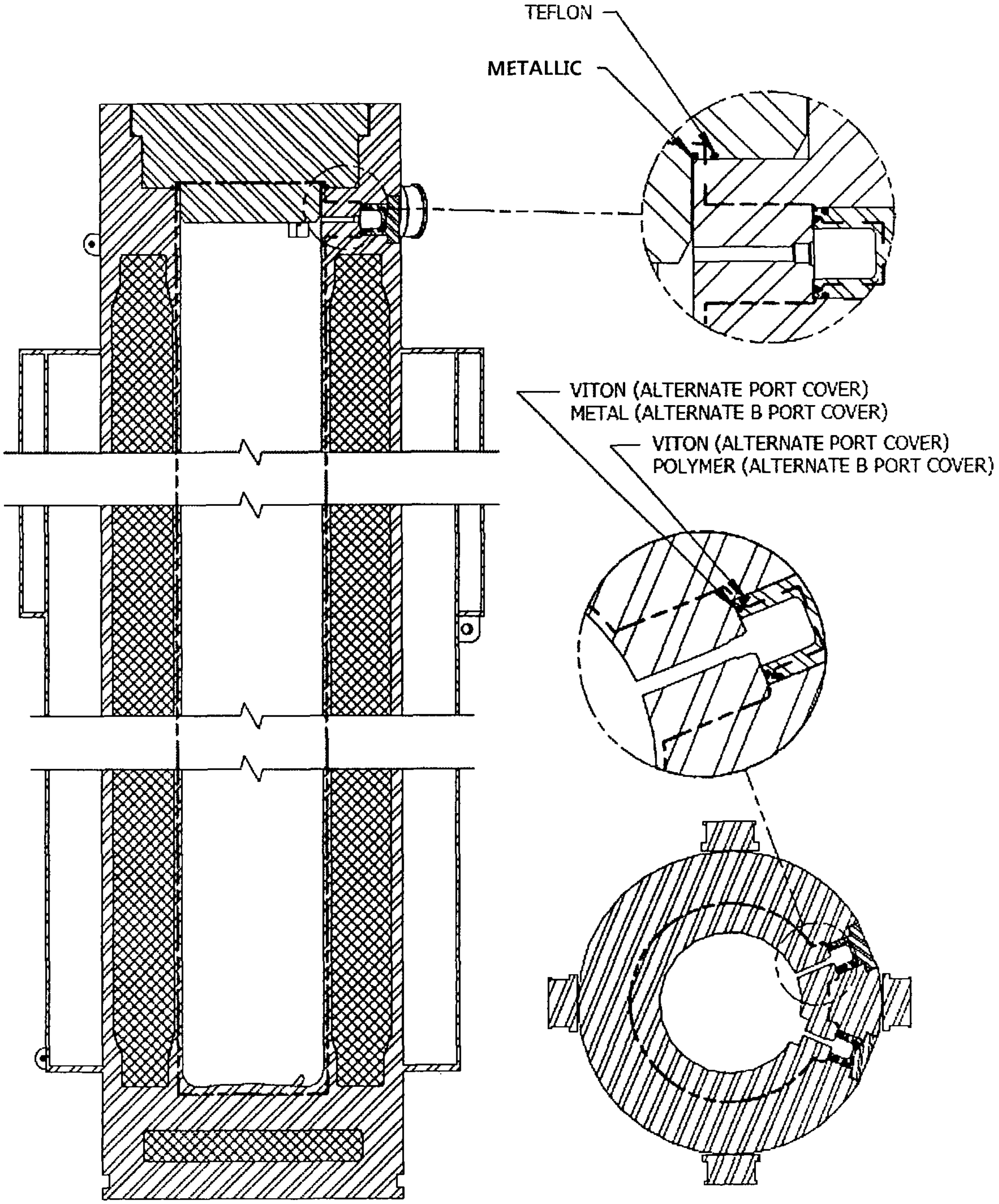
The leakage tests described in Section 8.1.3 verify that the lid and port cover seal leakage rates do not exceed 2×10^{-7} cm^3/sec (helium).

Alternate port covers are retained by three 3/8 - 16 UNC bolts, each tightened to 100 ± 10 in-lb of torque. The bolt material for these port covers is SA-193, Grade B6 high alloy steel. The Alternate B port cover is retained by three 3/8 - 16 UNC bolts, made from SB-637 Grade N07718 nickel alloy steel, each tightened to 280 ± 15 in-lb of torque.

The Alternate B port covers are required for the transport of TPBAR contents.

The Alternate port covers are required for the transport of HEUNL contents. Alternate port covers are required since the Alternate port cover Viton seals are compatible with the HEUNL nitrate content. [redacted]

Figure 4.1-1 Cask Containment Boundary



4.2 Containment Requirements for Normal Conditions of Transport

The NAC-LWT cask must maintain a radioactivity release rate less than 10^{-6} A_2/hr under normal conditions of transport, as required by 10 CFR 71.51 and IAEA Transportation Safety Standards (SSR-6). The maintaining of a leaktight containment for the NAC-LWT cask, per ANSI N14.5-1997, satisfies this condition. ANSI N14.5-1997 specifies and defines a reference (air at standard conditions) leakage rate of 1×10^{-7} ref.cm^3/s as leaktight. The equivalent allowable helium leakage rate at reference conditions is 2×10^{-7} cm^3/s (helium), with a minimum helium leak test sensitivity of 1×10^{-7} cm^3/s (helium).

For the transport of TPBAR contents, a leaktight containment boundary provided by metal containment seals is required. Therefore, for the transport of TPBARs under the package designation of USA/9225/B(M)-96, Alternate B port covers with metal seals are required to be installed.

The structural and thermal evaluations of the NAC-LWT are provided in Chapters 2 and 3, respectively. Results of these evaluations demonstrate that cask containment is maintained as leaktight during normal conditions of transport and hypothetical accident conditions. Therefore, the package satisfies the containment requirements of 10 CFR 71.51.

4.2.1 Containment of Radioactive Material

The 10 CFR 71 limit for the release of radioactive material under normal conditions of transport of 10^{-6} A_2/hr is assured by the maintenance of a leaktight containment boundary in accordance with ANSI N14.5-1997.

4.2.2 Pressurization of Containment Vessel

The maximum pressure in the cask during normal conditions of transport for other than TPBAR and HEUNL content payloads is calculated by using the methodology presented in Section 3.4.4. Assumptions underlying the calculations for contents other than TPBAR and HEUNL are that during normal conditions of transport, 3% of the fuel rods may fail and that 30% of the fission gases in the rods are releasable. The free volumes and resulting pressures are tabulated in Table 4.2-1. In addition, for LWR high burnup rods, 56% of the rods with oxide layers greater than 70 micrometers (14 rods) are assumed to fail during transport. This is conservative since fuel rods classified as damaged may have released fission and charge gases prior to transport. Failed rods are assumed to have released the fission gas prior to transport. The cask cavity is backfilled to 1 atm with 99.9% pure helium gas.

The gas volume (e.g., plenum and pellet to cladding gap) inside the fuel rods is conservatively neglected when calculating the cask free volume. The maximum normal operating pressure (MNOP) of the cavity for the PWR fuel configuration is 1.99 atm. The maximum normal condition cavity pressure for the 25 intact PWR/BWR high burnup fuel rod contents is 2.1 atm. The maximum normal condition cavity pressure with a 56% fuel rod failure rate is 3.2 atm for the 25 BWR high burnup rods and 3.0 atm for the 25 PWR high burnup rods.

Pressure evaluations in Section 3.4.4.8 demonstrate that the MNOP is less than 50 psig for aluminum-based nuclear fuels.

MNOP for the transport of up to 300 production TPBARs (including up to 2 prefailed rods) is conservatively determined in Section 3.4.4.5 as 289 psig. The TPBAR normal condition pressure assumed clad failure of all 300 TPBARs during transport. The pressure for the TPBAR content condition of 55 segmented TPBARs contained in a waste container and 25 TPBARs contained in a PWR/BWR Rod Transport Canister is bounded by the 300 TPBAR MNOP.

[redacted]

4.2.3 Containment Criteria

The standard leak rate for NAC-LWT transports of 1×10^{-7} ref.cm^3/sec represents the maximum leak rate allowed if the seals were to be tested with air at an upstream pressure of 1 atm and a downstream pressure of 0.01 atm at a temperature of 25°C. This is the maximum allowable leak rate for the containment system fabrication verification, periodic and maintenance leak tests described in Section 4.1 and in Chapter 8.

The NAC-LWT leaktight containment criteria, per ANSI N14.5-1997, is 1×10^{-7} ref cm^3/s, which is equivalent to a helium leak rate of less than, or equal to, 2×10^{-7} std cm^3/sec (helium) under test conditions. The minimum test sensitivity is 1×10^{-7} cm^3/s (helium).

Combining the permeation equations with an activity density of 0.16 Ci/cc, resulting from the release of 55 Ci per event failed rod and 0.199 moles of tritiated water for each prefailed rods, and

T = 572K – Maximum accident temperature for the seals per Table 3.5-1

Φ_0 = 7.42×10^{-2} [LLNL Report UCRL-53441] (stainless steel port seal), 2.10×10^{-2} [Fusion Science and Technology] (inconel lid seal)

E_Φ/R = 7,700 (stainless steel port seal), 7490 [Fusion Science and Technology] (inconel lid seal)

l = 0.012 inch for the port cover seal (only considering the stainless steel portion of the seal) and 0.032 inch for the lid seal

P_p = 0.15 atm – tritium partial pressure in the cask cavity based on the cask free volume, accident condition temperature, and a release of 55 Ci of tritium per event failed rod (conservative modeled as isotope not molecular tritium) and 0.199 moles of tritiated water from the prefailed rods)

yields an approximate release through seal permeation of 5 Ci/week compared to the allowable accident release rate of 1.1×10^{3} Ci/week ($1A_2$/week based on an A_2 value for tritium of 1.1×10^{3} Ci).

Actual permeation release rates would be significantly lower as the accident temperatures are short term, with elevated temperatures at the seal locations returning to normal condition temperatures within an hour of the fire.

Similar calculations are performed for the 55 equivalent TPBARs, in segments and debris, which may release up to 100% of the tritium contained in the pellets during transport. The pellet tritium content represents approximately 40% of the tritium quantity in the TPBAR. At NAC-LWT normal and accident conditions temperatures, the TPBAR components release tritium primarily as tritiated water with only a small fraction (maximum 2%) as gaseous tritium (see Appendix 1-B of Chapter 1). Gaseous tritium represents the basis for the seal permeation evaluation. During a one-year transport, an additional maximum 1% of the tritiated water may undergo radiolysis and dissociate. Conservatively applying a maximum 3% release rate to the 55 equivalent TPBAR total inventory of 66 grams (1.2 grams per rod) yields an inventory of 0.33 moles T_2. Seal permeation rates based on the conservative temperatures discussed in the previous paragraphs and a 3% tritium gas release are 6.5×10^{-6} Ci/hr, normal conditions, and 1.06 Ci/week, accident conditions. A gaseous release of over 90% of the 1.2 grams per rod tritium inventory is required to exceed normal condition allowables at the conservative seal temperature of 222°F. A 100% gaseous release and resulting tritium permeation through the cask seals meets accident condition limits. Reducing seal temperatures less than 5°F, to account for a significantly lower decay heat payload (0.127 kW for the waste container TPBARs versus 1.05 kW on which the 222°F temperature is based), permits a normal condition release of 100% of the tritium in gaseous form while meeting the 10^{-6} A_2/hr allowable.

4.3.2.3 HEUNL Containment

[redacted]

4.3.3 Tritium Contamination Issues

Precautions will be taken to minimize the risk of excessive contamination of NAC-LWT casks during the loading and unloading of TPBAR contents to ensure the reusability of the NAC-LWT casks for transport of non-TPBAR contents. In addition to ensuring the safe handling of TPBAR contents, additional cavity gas and internal and external removable contamination surveys for tritium contamination will be implemented at all TPBAR loading and unloading facilities. The specific monitoring methods and levels of contamination to which the cask surfaces must be decontaminated are defined in the TPBAR loading and unloading procedures in Chapter 7. In addition, the TPBAR procedures also include precautions for users to observe when loading, unloading and handling TPBARs.

The procedures and precautions comply with the recommended practices of NUREG-1609, Supplement 2. The results of previous loading and unloading experiences regarding the measurement of tritium gas and contamination levels are provided in the PNNL letter in Section 1.5, Appendix 1-G of this SAR.

NAC-LWT cask units used for TPBAR transports shall comply with the specified contamination levels, or other non-TPBAR users will be advised to incorporate tritium monitoring requirements into their survey procedures and radiological control program.

4.5.5 Containment Analysis of ANSTO Basket Payloads and ANSTO-DIDO Payloads

Payloads evaluated in the ANSTO basket are spiral fuel assemblies similar in design to the DIDO assemblies discussed in Section 4.5.7, and MOATA plate bundles similar in design to MTR assemblies discussed in Section 4.5.5. The ANSTO basket is a slightly modified version of the DIDO basket, with each basket containing seven fuel tubes designed to hold one fuel assembly or plate bundle in each fuel tube.

Parameter	DIDO Basket	ANSTO Basket
Fuel Assembly Openings	7	7
Fuel Tube OD (inch)	4.25	4.375
Fuel Tube Wall Thickness (inch)	0.120	0.125

The DIDO basket contains aluminum heat transfer components, while the ANSTO basket contains additional support disks. Overall, there are no significant free volume differences between the empty cask assembly configurations.

MOATA plate bundles, while displacing more free volume than DIDO assemblies, are limited to maximum burnups of 30,000 MWd/MTU and a minimum cool time of 10 years, resulting in source terms a small fraction of the DIDO payloads evaluated in Section 4.5.7. MOATA plate bundles, therefore, do not represent a containment-limiting payload configuration.

Spiral fuel assemblies are limited to the cool time curve of the 18-watt MEU DIDO fuel assemblies. As demonstrated in Chapter 5, Section 5.3.15, this produces a significantly lower source for the spiral fuel than the 18-watt DIDO assembly. The lower source for the spiral fuel is attributed to a higher fissile material mass in the DIDO evaluation (190 g ^{235}U versus 160 g ^{235}U for the spiral fuel), at identical cool time and a maximum depletion of 70%, in conjunction with a lower DIDO enrichment (40 % ^{235}U for the MEU DIDO fuel versus 75% ^{235}U enrichment in the spiral fuel calculations). For containment evaluations, the higher heat load, 25-watt DIDO configuration was evaluated, providing additional margin for the spiral fuel assemblies. When compared to the DIDO payload, the spiral assembly payload, therefore, has a significantly lower source of radionuclides at a similar cask free volume. As a result, the DIDO fuel assembly containment evaluation bounds the spiral fuel.

As the DIDO containment evaluations bound ANSTO spiral and MOATA payloads, the DIDO evaluations also bound combined payloads. DFCs in seven out of a maximum 42 tubes do not displace a significant cask-free volume (~2%) and, therefore, do not affect the conclusion that the DIDO evaluation is bounding.

4.5.6 Pressure and Flammability Evaluation of HEUNL Container

During transport operations of the HEUNL, solution gas generation and the resulting pressurization of the container must be considered. Also to be considered is a limitation of hydrogen gas volume fraction.

4.5.6.1 Pressurization

No significant gas generations will occur from the container as a result of galvanic or chemical reactions of the low carbon stainless steel transport container with its contents. A container of stainless steel at less than 0.03 wt% carbon is compatible with the solution and has been used as the [redacted] At transport temperatures, no significant corrosion of the container will occur and no significant gases will be generated. Radiolysis of the solution will generate both hydrogen and oxygen gas. No significant amount of nitrogen will be generated due to radiation exposure.

[redacted]

Therefore, maximum pressure during transport of the solution for a period of up to one year is limited to < 60 psia normal and <80 psia accident.

4.5.6.2 Flammability

Both hydrogen and oxygen are reabsorbed into the solution by various chemical processes. Depending on acid content and temperature of the solution. a large range of steady state hydrogen concentrations are feasible. [redacted] a steady state hydrogen concentration under 5% will occur inside the container.

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in each plate. To remain below a k_s of 0.95, the plates are limited to 18 g ^{235}U each. Evaluating the fuel at a lower enrichment (50 wt % ^{235}U) shows that the HEU (94 wt% ^{235}U) is bounding. To demonstrate that a lower number of plates in the cask is less reactive at the 18g ^{235}U limit, Set D evaluates a reduced number of plates at maximum (optimal) pitch. Reactivity for these cases is significantly lower than that of the 23-plate case. Set E evaluates various perturbations to the input parameters of the model to demonstrate that the given input is bounding. As shown, there is no significant impact of uranium weight percent changes, modeling an aluminum extension to the width of the fuel plate, or shifting of the aluminum side plates within the plane of the basket. Reactivity decreases with a decreasing plate pitch, an extension of the element length by unfueled plate or end fitting, or changes to the plate thickness by either increasing the fuel core material thickness or the clad thickness. Reactivity increases by decreasing the element side plate thickness, and decreases significantly when inserting two additional aluminum plates approximating the configuration with a loose fuel plate canister inserted into the model. Differences in reactivity (Δk_{eff}) for set C, D, and E are taken from the 56 cm active fuel height shifted model with 18 g ^{235}U.

Set F

Not all MTR fuel plates contain less than 18 g ^{235}U. The HFBR fuel, in particular, contains up to 19.5 g ^{235}U per plate but is limited to 18 fuel plates. An analysis is therefore performed with a bounding 19 plate and 20 g ^{235}U per plate model. The k_s for this system is below 0.95.

Set G

A limited quantity of MTR plates exist with an active fuel width greater than the 6.6 cm evaluated. Therefore, additional analysis is performed at a 7.3 cm active fuel width. Based on the evaluation of an 18 g ^{235}U per plate model, the reactivity of this system is significantly higher than that of the 6.6 cm width case. Therefore, fissile quantity per plate is restricted to 16.5 g ^{235}U.

Set H

Low enriched uranium fuel (LEU) can reach a per plate loading up 21 g ^{235}U. Therefore, evaluations at 7.3 cm and 6.6 cm active fuel width are performed with 23 plates at 22 g of LEU material (maximum 25 wt% ^{235}U). The 7.3 cm active fuel width resulted in a reactivity higher than the allowed limit. The 22 g ^{235}U plates of LEU material are, therefore, restricted to a maximum active fuel width of 6.6 cm.

Set I

NISTR fuel presents an exception to the standard MTR fuel element, since each plate has two fuel sections that are separated by a short section of non fuel-bearing aluminum. These plates may be cut at the aluminum strip, with both sections inserted into a basket opening. This evaluation demonstrates that both an intact and cut element would remain below the licensing limits at 22 grams per plate.

Sets A and B determined that a minimum active fuel should be applied as a constraining parameter. This parameter sets a lower bound on the fissile material axial linear density (g ^{235}U/cm). At a fixed linear fissile material density, while maintaining other fuel bounding parameters, reactivity of the system will be reduced as fissile material is removed from the system. Table 6.4.3-21 footnote 6 credits this system behavior by allowing lower active fuel height when reducing allowed fissile mass per plate/assesmbly proportionally (i.e., reducing fissile material content by the ratio of a specific fuel assesmbly's active fuel height to that of the 56 cm reference minimum height.)

6.4.3.13 MTR Fuel Elements with High Fissile Material Loading

This section determines the requirements for loading a high fissile material content MTR fuel element with up to 20 g ^{235}U per plate (460 g ^{235}U per element based on 23 plates). Section 6.4.3.12 has demonstrated that the HEU fuel is more reactive than LEU and MEU fuel. Therefore, only the HEU fuel is evaluated in this section. Additional evaluations are provided with the limiting characteristics of an HEU MTR element containing up to 21g ^{235}U per plate.

The models employed are similar to those of Section 6.4.3.12 with any differences originating in the modified minimum plate thickness and the amount of axial non-active fuel region material (or spacer material) in the basket. Section 6.4.3.12 relied on a minimum plate thickness of 0.115 cm and a minimum 0.7 cm offset of the active fuel region to the end of the fuel element. The offset of 0.7 cm assured an active fuel region separation of 2.67 cm (2 x 0.7 cm plus the 1.27 cm base plate). Section 6.4.3.12 analyses have shown that increasing the axial separation distance between the fissile material or increasing plate thickness will decrease system reactivity. Both of these effects are taken credit for in the evaluation of the high fissile material loaded MTR element. The minimum plate thickness and element axial end region hardware length are adjusted until k_s is below 0.95.

Evaluations for various amounts of axial hardware material reveal that with only this change, a minimum 4 cm offset, 8 cm total hardware (spacer material) must be provided for the system reactivity to remain below 0.95 (Table 6.4.3-23). Similarly, Table 6.4.3-23 shows that increasing the fuel plate thickness to 0.123 cm (1.23 mm) is insufficient by itself to reduce reactivity below 0.95. A combination of 2 cm of hardware at the top and bottom of the element,

Table 6.4.3-21 Baseline MTR Bounding Configurations

Parameter(1)	Generic	NISTR(2)
Plate thickness	≥ 0.115 cm	≥ 0.115 cm
Clad thickness	≥ 0.02 cm	≥ 0.02 cm
Number of fuel plates	≤ 23(3)	≤ 17
^{235}U content per plate	≤ 18 g(3,4,5)	≤ 22 g
Enrichment wt % ^{235}U	≤ 94(4)	≤ 94
Active width	≤ 6.6 cm(5)	≤ 6.6 cm
Active fuel height	≥ 56 cm(6)	≥ 54 cm
Maximum reactivity (k_s)	0.9482	0.9461

Notes:

(1) Loose fuel plates meeting the requirements in this table must be loaded into a MTR plate canister.

(2) Fuel plates may be cut in half with each half limited to 11g ^{235}U and an active fuel length between 27 and 30 cm.

(3) At a 19 fuel plate maximum, the plates are limited to 20g ^{235}U per plate.

(4) LEU fuel plate with up to 22g ^{235}U may be loaded at a maximum enrichment of 25 wt % ^{235}U.

(5) At a maximum active fuel width of 7.3 cm, the plates are limited to 16.5g ^{235}U.

(6) Active fuel height below 56 cm is allowed provided the axial (height) fissile material linear density is maintained. This is achieved by a proportionate reduction in the maximum allowed fissile material mass per plate by the ratio of the fuel plate fissile material height to the 56 cm reference height. As an example, at a minimum 42 cm active fuel height, the generic 18 g ^{235}U maximum plate (56 cm minimum active fuel height) would be reduced to an allowable maximum of 13.5 g ^{235}U (18g ^{235}U * 42/56) per plate. Reduced fuel heights may similarly be applied to the fuel configurations described in Notes 2, 3 and 4.

Table 6.4.3-22 High Fissile Mass MTR Fuel – Bounding Parameter Analysis

	Variation From Baseline (Generic) MTR		
Parameter	**Increased Plate Thickness and Fissile Mass** [1]	**Increased Plate Thickness and Fissile Mass and Decreased Number of Plates**	**Increased Fissile Mass and Decreased Number of Plates**
Plate thickness [cm]	≥ 0.123	≥ 0.200	≥ 0.115
Clad thickness [cm]	≥ 0.02	≥ 0.02	≥ 0.02
Number of fuel plates	≤ 23	≤ 19	≤ 17
^{235}U content per plate [g]	≤ 20	≤ 21	≤ 21
Enrichment [wt % ^{235}U]	≤ 94	≤ 94	≤ 94
Active Width [cm]	≤ 6.6	≤ 6.6	≤ 6.6
Active Fuel Height [cm]	≥ 56	≥ 56	≥ 56
Maximum reactivity (k_s)	0.9488	0.8753	0.9451

(1) Requires a minimum 4 cm of fuel element hardware (or spacer material) separating the fuel segments axially.

Package Regional Densities

The composition densities (g/cc) and nuclide number densities (atm/b-cm) evaluated in subsequent criticality analyses are shown in Table 6.7.2-7.

6.7.2.3 Criticality Calculations

This section presents the criticality analyses for the NAC-LWT cask with HEUNL containers. Criticality analyses are performed to satisfy the criticality safety requirements of 10 CFR Parts 71.55 and 71.59, as well as IAEA SSR-6.

The maximum reactivity configuration is determined by implementing a series of studies. The series of studies are designed to meet 10 CFR 71.55 (b) and (e) requirements on normal and accident condition single casks. The single cask analysis by regulation must consider a fully water reflected package and be at optimum physical configuration and moderation. Each study will retain the maximum reactivity configuration from the previous study.

After the single cask analysis is complete, cask array analysis is performed to meet 10 CFR 71.59 requirements. Per the standard review plan (NUREG-1617) the 10 CFR 71.59 requirements are met by evaluating a cask array with dry cask interior and cask exterior for normal condition and optimum interior and exterior moderated array for accident conditions (see Sections 6.5.5 and 6.5.6 in NUREG-1617). [redacted] As the HEUNL containing cask array is evaluated as an infinite array, the exterior to the array condition is not applicable.

[redacted]

10 CFR 71.55 Scoping Calculation

In compliance with 10 CFR 71.55 the scoping calculations are based on a single cask with a 20 cm boundary from the cask exterior dimensions. The space between cask and boundary is flooded with full density water to produce a fully water reflected system.

Initial scoping analysis evaluates cask interior flooding conditions. Due to the system containing little cavity volume for moderation, flooding conditions have negligible effects on reactivity. Normal and accident configuration casks are expected and are confirmed to be similar from a neutronics perspective. Geometry differences are limited to the presence/absence of the neutron shield. For a fully water reflected cask, differences in neutron tracking between the models are those associated with ethyl glycol/water in the first 5 inches of reflector and Monte Carlo differences for tracking through the additional reflector.

Table 6.7.2-8 contains a summary of the scoping results. Maximum reactivity is obtained by a void cask interior. Either normal or accident condition cask geometry can be chosen for the following evaluations without a statistically significant difference in result. For this calculation the accident condition cask geometry was chosen.

10 CFR 71.55 Uranyl Nitrate H/U Study

As shown in the scoping analysis, the nominal HEUNL solution k_{eff} is below limits. The nominal HEUNL solution is defined for this criticality evaluation as the loaded solution. The worst case configuration for the HEUNL includes all non-fissile nitrates precipitating out from the solution leaving only a uranyl nitrate-water mixture.

[redacted]

[redacted]

10 CFR 71.55 Uranyl Nitrate Shift and Cask Cavity Moderator Study

[redacted]

10 CFR 71.55 Optimum Tolerance Studies

[redacted]

[redacted]

Results for the tolerance study are shown in Table 6.7.2-14. The tolerance results show no statistically significant increase for any tolerance. Therefore, tolerances will not be applied in the maximum configuration.

MCNP Validated Libraries

The ZAID library for lead, 82000.50c, was not included in the MCNP validation highly enriched uranyl nitrates (see Section 6.5.4). Lead is used as a shield material in the NAC-LWT MCNP model. Exterior reflector material validation is not a significant issue for moderated systems where fuel region neutronic interaction, not reflection, is the primary reactivity driver.

The ZAID library for mercury, 80000.42c, was not included in the MCNP validation of highly enriched uranyl nitrates. Mercury is a strong absorber with capture cross section, σ_γ, of 376 b. Therefore, mercury is replaced in the MCNP model with aluminum ($\sigma_\gamma = 0.23$ b) to account for the lack of validation for mercury. The previously established maximum reactivity configuration is retained for this study. As shown in Table 6.7.2-15, removal of mercury statistically increases system reactivity.

All other evaluated libraries are accounted for in the validation.

10 CFR 71.55 Maximum Reactivity Summary

Based on the previous studies, the following conditions are bounding for the maximum reactivity configuration:

- Uranyl nitrate – water mixture in [redacted]
- Uranyl nitrate – water mixture optimally moderated
- Uranyl nitrate mixtures shifted in alternating configuration
- Dry cask cavity
- Mercury removed from model

Maximum system reactivities are determined with this maximum reactivity configuration under normal (neutron shield present) and accident (no neutron shield) conditions. As seen in Table 6.7.2-16, the maximum reactivity is 0.8952 and below the USL of 0.9366.

10 CFR 71.55 (b) (3) requires an evaluation of the NAC-LWT with the containment system fully reflected by water. The containment for the NAC-LWT is the cask inner shell. While no operating condition results in a removal of the cask outer shell and led gamma shield, the most reactive case is re-evaluated by removing the lead and outer shells (including neutron shield), and reflecting the system by water at full density. Using the maximum reactivity configuration, the calculated $k_{eff}+2\sigma$ is 0.86235, which is significantly below that of the full cask water reflected model (i.e., neutron reflection produced by the lead gamma shield and outer steel cask shell produces a higher reactivity system than that produced by a water reflector.

10 CFR 71.59 Maximum Reactivity Summary

10 CFR 71.59 (a) (1) requires the evaluation of five times "N" normal condition packages. 10 CFR 71.59 (a) (2) requires the evaluation of two times "N" accident condition packages with optimum moderation. Both normal and accident conditions specified by the CFR are satisfied with the maximum reactivity configuration defined for the 10 CFR 71.55 evaluation. The model is modified by applying a reflecting surface at the cask exterior surface. This option produces an infinite array of casks. As seen in Table 6.7.2-17, while slightly increasing system reactivity above that of a single cask, both results are below the USL of 0.9366.

The resulting CSI for an infinite array of NAC-LWT casks with HEUNL is 0.

Water Reflector and Canister Dimensions

[redacted]

6.7.2.4 Code Validation and Area of Applicability

Critical benchmarks and USL are discussed in detail in Section 6.5.4. The following evaluates the applicability of the USL to HEUNL.

The area of applicability (AoA) for the validation is compared to the system parameters for the NAC-LWT with HEUNL most reactive case. The USL, 0.9366, used for this calculation is based on the energy of the average neutron lethargy causing fission (EALCF). Table 6.7.2-18 shows the validated range of EALCF. The USL for the validation is the minimum USL from the EALCF range. The EALCF for the most reactive HEUNL case is 0.04 eV and is within the validation range.

6.7.2.5 Allowable Cask Loading

Based on the results of the previous sections, loading of 4 HEUNL containers is allowed in the NAC-LWT. Maximum content of the container is limited to 17 gallons of solution with a maximum 7.2 g ^{235}U per liter. The transport package has been found to be in compliance with 10 CFR 71.59 and 10 CFR 71.55. The maximum reactivity, including two sigma, of 0.9071 for the transport package is subcritical. This evaluation has considered an H/U study, shift study, moderator study, and container tolerance study. The transport package has been designated a CSI of 0. To achieve HEUNL container fill capacity, dilution of the HEUNL container is allowed.

Figure 6.7.2-1 VISED X-Z Cross-Section of NAC-LWT with HEUNL

[redacted]

Figure 6.7.2-2 VISED X-Z Cross-Section of HEUNL Container Detail

[redacted]

Figure 6.7.2-3 VISED X-Y Cross-Section of NAC-LWT with HEUNL

[redacted]

Figure 6.7.2-4 Axial Sketch of NAC-LWT with HEUNL

[redacted]

Figure 6.7.2-5 Radial Sketch of NAC-LWT with HEUNL

[redacted]

Figure 6.7.2-6 Axial Sketch of HEUNL Container

[redacted]

Figure 6.7.2-7 Reactivity Results by HEUNL [redacted] H/U Ratio

[redacted]

Figure 6.7.2-8 Reactivity Results by HEUNL [redacted] H/U Ratio

[redacted]

Figure 6.7.2-9 VISED X-Z Cross-Section of HEUNL with Alternating Shift

[redacted]

Figure 6.7.2-10 VISED X-Z Cross-Section of HEUNL with Inward Shift

[redacted]

Figure 6.7.2-11 Cask Cavity Moderator Study Reactivity Results for HEUNL

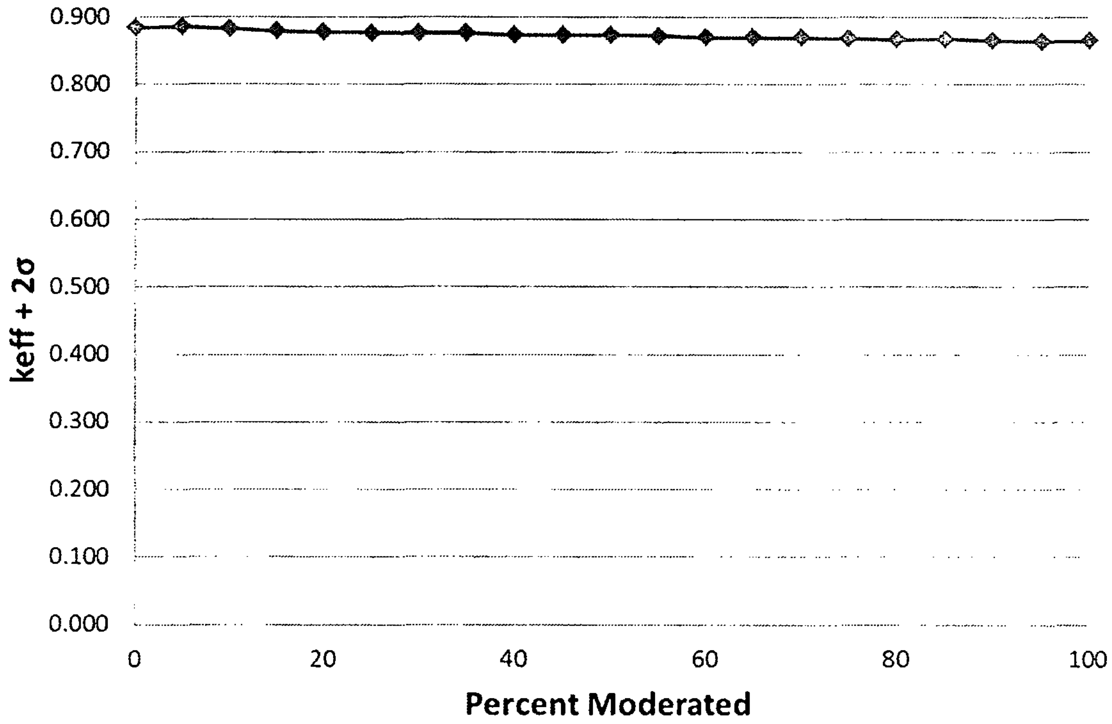

Table 6.7.2-1 Composition of HEUNL Solution

Chemical Compound	Concentration (mol/L)	Concentration of Metal Ion (g/L)
HNO_3	0.96	N/A
$Al(NO_3)_3$	1.5	40.5
$Hg(NO_3)_2$	0.053	10.6
$Fe(NO_3)_3$	0.019	1.06
$Cr(NO_3)_3$	0.005	0.26
$Ni(NO_3)_2$	0.003	0.18

Table 6.7.2-2 HEUNL Evaluated Model Composition

				Concentration (g/L)			
Solution	Metal Ion	mol/L	A_r (metal)	Ion	N	O	Solution
HNO_3	H	0.96	1.00794	0.97	13.45	46.06	60.48
$Al(NO_3)_3$	Al	1.5	26.982	40.5	63.03	215.92	319.42
$Hg(NO_3)_2$	Hg	0.053	200.59	10.6	1.48	5.09	17.20
$Fe(NO_3)_3$	Fe	0.019	55.845	1.06	0.80	2.73	4.59
$Cr(NO_3)_3$	Cr	0.005	51.9961	0.26	0.21	0.72	1.19
$Ni(NO_3)_2$	Ni	0.003	58.6934	0.18	0.08	0.29	0.55
$UO_2(NO_3)_2$	U	0.0337	235.1738	7.925	0.94	4.31	13.18
				Total:	80.00	275.12	416.61

Table 6.7.2-3 HEUNL Actinide Concentration

	DI	Modeled	
Nuclide	Conc. (g/L)	Conc. (g/L)	wt. %
^{234}U	1.23E-01	--	--
^{235}U	7.00E+00	7.20E+00	90.85%
^{236}U	1.53E-01	--	--
^{238}U	4.49E-01	7.25E-01	9.15%

Table 6.7.2-4 Evaluated HEUNL Isotopic Composition

Element	Z	A	Conc. (g/L)	wt.%
H	1	1	9.676E-01	0.074%
Al	13	27	4.047E+01	3.113%
Hg	80	NA[1]	1.063E+01	0.818%
Fe	26	NA	1.061E+00	0.082%
Cr	24	NA	2.600E-01	0.020%
Ni	28	NA	1.761E-01	0.014%
N	7	14	8.000E+01	6.154%
O	8	16	2.751E+02	21.163%
U	92	234	1.230E-01	0.009%
	92	235	7.200E+00	0.554%
	92	236	1.530E-01	0.012%
	92	238	4.490E-01	0.035%
Np	93	237	1.720E-04	0.000%
Pu	94	239	5.630E-04	0.000%
	94	240	1.070E-05	0.000%
Total - Nitrates			4.166E+02	32.047%
Water Content				
H	1	1	9.815E+01	7.550%
O	8	16	7.852E+02	60.402%
Total - Water			8.834E+02	67.953%
Total - HEUNL			1.300E+03	100.0%

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[1] Natural abundance

Table 6.7.2-5 Evaluated HEUNL Properties

Description	Value
HEUNL volume in cask (L / gal)	257 / 68.0
HEUNL volume in container (L / gal)	64.3 / 17.0
HEUNL mass in cask (kg)	334
HEUNL mass in container (kg)	83.5
Uranyl Nitrate mass in cask (kg)	3.39
Uranyl Nitrate mass in container (kg)	0.848
U concentration (g/L)	7.92
^{235}U concentration (g/L)	7.20
U mass in cask (kg)	2.04
U mass in container (kg)	0.509
^{235}U mass in cask (kg)	1.85
^{235}U mass in container (kg)	0.463

Table 6.7.2-6 HEUNL Container Design Parameters

[redacted]

Table 6.7.2-7 HEUNL Analysis Compositions and Number Densities

Material	U-Al	H_2O	304 Stainless Steel	Pb	Al
Density, g/cc	1.300	0.9982	7.920	11.344	2.702
Density	atoms/b-cm				
Uranium-235	1.845E-05				
Uranium-238	1.834E-06				
Nitrogen	3.439E-03				
Oxygen	3.992E-02	3.340E-02			
Hydrogen	5.922E-02	6.679E-02			
Chromium					
Manganese	3.011E-06		1.747E-02		
Iron			1.741E-03		
Nickel	1.144E-05		5.854E-02		
Carbon	1.807E-06		7.739E-03		
Silicon			3.185E-04		
Phosphorus			1.702E-03		
Lead			6.947E-05		
Aluminum				3.297E-02	

Table 6.7.2-8 HEUNL Scoping Reactivity Results

Condition	**1**	**2**	**3**	**4**
Interior	Dry	Wet	Dry	Wet
Exterior	Wet	Wet	Wet	Wet
Condition	Normal	Normal	Accident	Accident
$k_{eff}+2\sigma$	0.3359	0.3277	0.3359	0.3271

Table 6.7.2-9 Sample HEUNL Isotopic Composition for [redacted] Uranyl Nitrate – Water Mixture

Element	Z	A	Conc. (g/L)	Mass (g/container)	wt.%
N	7	14	8.000E+01	6.074E+01	0.577%
O	8	16	2.751E+02	2.774E+02	2.636%
U	92	234	1.230E-01	7.914E+00	0.075%
	92	235	7.200E+00	4.633E+02	4.402%
	92	236	1.530E-01	9.845E+00	0.094%
	92	238	4.490E-01	2.889E+01	0.275%
Total - Nitrates			4.166E+02	8.482E+02	8.059%
Water Content					
H	1	1	9.815E+01	1.075E+03	10.216%
O	8	16	7.852E+02	8.601E+03	81.725%
Total - Water			8.834E+02	9.676E+03	91.941%
Total - HEUNL			1.300E+03	1.052E+04	100.0%

Table 6.7.2-10 HEUNL Reactivity Results for [redacted] of Uranyl Nitrate – Water Mixtures

[redacted]	H/U	$k_{eff}+2\sigma$
		0.3359
4.6	2	0.2329
6.0	29	0.3960
7.8	90	0.5985
9.8	201	0.7514
11.1	302	0.8158
11.6	347	0.8314
12.1	397	0.8437
12.6	451	0.8544
13.0	498	0.8570
13.4	547	0.8618
13.8	600	0.8605
14.2	655	0.8596
14.5	699	0.8560
14.8	745	0.8506
15.1	791	0.8443
15.5	855	0.8348
15.8	903	0.8244
16.4	1003	0.8076
17.5	1197	0.7713

Table 6.7.2-11 HEUNL Reactivity Results for [redacted] of Uranyl Nitrate

Height (cm)	H/U	$k_{eff}+2\sigma$
		0.3359
0.7	3	0.3233
1.4	30	0.3761
3.0	90	0.4779
5.9	200	0.6212
8.5	300	0.7089
9.8	350	0.7405
11.1	400	0.7641
12.5	450	0.7848
13.8	500	0.7989
15.1	550	0.8114
16.4	600	0.8183
17.8	650	0.8229
19.1	700	0.8243
20.4	750	0.8251
21.7	800	0.8251
23.0	850	0.8223
24.4	900	0.8187
27.0	1000	0.8099
32.3	1200	0.7853

Table 6.7.2-12 HEUNL Reactivity Results for Fissile Material Shift Study

	Parameter		k_{eff}	σ	$k_{eff}+2\sigma$
Flooded Cask	[redacted]	Nom	0.8530	0.0009	0.8548
		In	0.8614	0.0009	0.8631
		Alt	0.8628	0.0009	0.8647
	[redacted]	Nom	0.8226	0.0008	0.8243
		In	0.8412	0.0008	0.8429
		Alt	0.8388	0.0009	0.8405
Dry Cask	[redacted]	Nom	0.8598	0.0010	0.8618
		In	0.8814	0.0009	0.8832
		Alt	0.8821	0.0009	0.8838
	[redacted]	Nom	0.8235	0.0008	0.8251
		In	0.8630	0.0009	0.8647
		Alt	0.8631	0.0008	0.8648

Table 6.7.2-13 HEUNL Reactivity Results for Cask Cavity Moderator Study

Density [g/cc]	k_{eff}	σ	$k_{eff} + 2\sigma$	Δk_{eff}/sigma
0.9982	0.8628	0.0009	0.8647	-15.0
0.9500	0.8627	0.0008	0.8644	-15.9
0.9000	0.8637	0.0009	0.8655	-14.2
0.8500	0.8655	0.0010	0.8674	-12.5
0.8000	0.8645	0.0009	0.8663	-13.9
0.7500	0.8667	0.0009	0.8684	-12.3
0.7000	0.8678	0.0009	0.8697	-10.9
0.6500	0.8681	0.0009	0.8698	-11.2
0.6000	0.8679	0.0008	0.8696	-11.7
0.5500	0.8704	0.0009	0.8723	-9.0
0.5000	0.8715	0.0009	0.8733	-8.2
0.4500	0.8711	0.0009	0.8730	-8.4
0.4000	0.8715	0.0009	0.8733	-8.4
0.3500	0.8746	0.0009	0.8763	-6.0
0.3000	0.8744	0.0009	0.8762	-5.9
0.2500	0.8752	0.0009	0.8769	-5.6
0.2000	0.8758	0.0010	0.8777	-4.7
0.1500	0.8774	0.0009	0.8792	-3.6
0.1000	0.8808	0.0009	0.8826	-1.0
0.0500	0.8834	0.0009	0.8852	1.1
0.00	0.8821	0.0009	0.8838	

Table 6.7.2-14 HEUNL Reactivity Results for Container Tolerance Study

Parameter		keff	σ	$k_{eff}+2\sigma$	Δk_{eff}	$\Delta k_{eff}/\sigma$
Container Bottom Thickness	Nom	0.8821	0.0009	0.8838	--	
	Min	0.8818	0.0009	0.8836	-0.0002	-0.2
	Max	0.8829	0.0009	0.8848	0.0010	0.7
Container Length	Nom	0.8821	0.0009	0.8838	--	
	Min	0.8840	0.0009	0.8859	0.0020	1.6
	Max	0.8805	0.0008	0.8821	-0.0017	-1.4
Container Top to Cavity Top Segment Length	Nom	0.8821	0.0009	0.8838	--	
	Min	0.8806	0.0009	0.8824	-0.0014	-1.1
	Max	0.8827	0.0009	0.8844	0.0006	0.4
Container Top to Bottom Plate Length	Nom	0.8821	0.0009	0.8838	--	
	Min	0.8805	0.0008	0.8821	-0.0017	-1.4
	Max	0.8822	0.0009	0.8840	0.0002	0.1

Table 6.7.2-15 HEUNL Reactivity Results for Mercury Removal

Parameter	k_{eff}	σ	$k_{eff}+2\sigma$	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nom	0.8821	0.0009	0.8838	--	--
Removed	0.8932	0.0009	0.8950	0.0112	8.9

Table 6.7.2-16 HEUNL Maximum Reactivity per 10 CFR 71.55

Geometry	k_{eff}	σ	$k_{eff}+2\sigma$
Normal Conditions per 10 CFR 71.55 (b)	0.8935	0.0009	0.8952
Accident Conditions per 10 CFR 71.55 (e)	0.8932	0.0009	0.8950

Table 6.7.2-17 HEUNL Maximum Reactivity per 10 CFR 71.59

Geometry	k_{eff}	σ	$k_{eff}+2\sigma$	CSI
Normal Conditions per 10 CFR 71.59 (a) (1)	0.8947	0.0009	0.8965	0
Accident Conditions per 10 CFR 71.59 (a) (2)	0.9053	0.0009	0.9071	0

Table 6.7.2-18 Validation Area of Applicability Comparison with HEUNL Results

Parameter	Uranyl Nitrate Validation	HEUNL
Fissile Form	Nitrate Solutions	Uranyl Nitrate
Moderator	Light Water, Tap Water, or None	Light Water
H/U Ratio	51.010 to 2050	547
EALCF (eV)	3.06E-02 to 5.26E-01	0.04

Table 6.7.2-19 HEUNL Reactivity Comparisons for Design Modification and Reflector Dimension Change

Geometry	Baseline Evaluation k_{eff}	Modified Design / Reflector 30 cm k_{eff}	Δk	$\Delta k/\sigma$
Normal Conditions per 10 CFR 71.55 (b)	0.8935	0.8940	0.0005	<1
Accident Conditions per 10 CFR 71.55 (e)	0.8932	0.8935	0.0003	<1
Normal Conditions per 10 CFR 71.59 (a) (1)	0.8947	0.8954	0.0007	<1
Accident Conditions per 10 CFR 71.59 (a) (2)	0.9053	0.9052	0.0001	<1

7 OPERATING PROCEDURES

This chapter describes the generic operating procedures for loading, unloading and preparing the NAC-LWT package for transport. These procedures shall be implemented to ensure the package is used in accordance with Certificate of Compliance (CoC) No. 9225 for the NAC-LWT packaging.

These procedures are based on generic site conditions and assume that the package arrives at the handling site with the appropriate internals installed in the cask. Additional operations and/or modifications (i.e., sequence of operations, use of parallel operations, etc.) to these procedures to address site-specific conditions may be required for each user's facility. These additional operations and/or modifications will be documented in site-specific procedures.

In addition, site-specific procedures may incorporate signoffs for activities or operational sequences as they are performed. Oversight organizations, such as Quality Assurance or Quality Control, may participate in certain package handling operations. The use of signoffs can assist the user in assuring that critical steps are not overlooked, that the package is handled in accordance with the CoC and Safety Analysis Report (SAR), and that appropriate records are retained as required by 10 CFR 71.91.

The NAC-LWT package is designed and certified to transport numerous fissile and radioactive contents, as described in the CoC, as a Type B(U)F-96 package. Certain radioactive contents, as described in the CoC, are required to be transported in a NAC-LWT assembled and tested in a leaktight containment configuration. The leaktight containment can be provided by either the Alernate port cover design with a Viton O-ring seal or by the Alternate B port cover design with a metallic seal.

The NAC-LWT is also certified for the transport of Tritium Producing Burnable Absorber Rod (TPBAR) contents, as described in the CoC, as a Type B(M)-96 package. NAC-LWT cask units designated for the transport of TPBAR contents require both leaktight containment and a high-pressure capable containment barrier. NAC-LWT casks for the leaktight transport of TPBAR contents shall be configured with Alternate B vent and drain port covers in accordance with the license drawings, and subjected to the additional hydrostatic test per the requirements of Section 8.1.2.

Conversely, NAC-LWT casks for the transport of HEUNL contents shall be configured with Alternate vent and drain port covers in accordance with the license drawings. No material release will occur from the HEUNL containers under normal or accident condition. In the context of defense in depth, [redacted] consideration of a hypothetical release of HEUNL material from the containers and compatibility with the HEUNL nitrate content.

Loaded shipments received at U.S. Department of Energy (DOE) facilities shall be receipt surveyed and monitored in accordance with DOE regulations. As required, the shipper will be notified of any survey or shipping discrepancy and the shipper will ensure appropriate regulatory notifications are completed.

When the package is handled in accordance with the procedures provided herein, and is loaded within the conditions of the CoC and the SAR, the resulting occupational exposures will be maintained as low as reasonably achievable (ALARA), as required by 10 CFR 20.

7.1 Procedures for Loading Packages

For the shipment of loaded packages, the cavity shall be dry, the contents and nameplate package identification, corresponding to the contents, shall be verified as correct, and the other applicable conditions of the Certificate of Compliance (CoC) shall be verified as met. Site-specific procedures for dry handling, when required, and loading of fuel assemblies and other authorized contents will be prepared to incorporate the dry transfer system components required to safely and efficiently load the NAC-LWT at each loading facility. Dry loading and transfer procedures are not specifically described in the individual loading procedures due to facility and required equipment variations. Content configurations may require spacers, baskets, basket inserts, canisters, etc., to support and/or control the content geometry during transport. The transport configurations identifying the specific contents and components required are specified in the license drawings. Solid, irradiated and contaminated hardware will generally be loaded wet utilizing the procedure guidance of Section 7.1.1. Alternatively, the solid, irradiated and contaminated hardware can be loaded dry utilizing dry loading procedures (i.e., per Section 7.1.2) modified to the requirements of the dry loading facilities.

Two port cover designs are available for use. The alternate port cover has an O-ring along the barrel and a Viton® O-ring on the inner end of the port cover. The alternate port cover was developed to provide a leaktight containment boundary and to facilitate ease of installation. The second port cover design is the Alternate B port cover that has two face seals on the inner end of the port cover. The Alternate B port cover was developed to provide a high-pressure and leaktight containment boundary and is required to be installed for the transport of TPBAR contents and other authorized contents requiring a leaktight containment capability (e.g., damaged TRIGA fuel and fuel debris and PWR MOX fuel rods). The two port cover designs can be used interchangeably for authorized contents not requiring a high-pressure containment boundary capability.

The alternate port cover bolts are torqued to 100 ± 10 inch-pounds. The Alternate B port cover bolts are torqued to 285 ± 15 inch-pounds to ensure compression of the metallic containment O-ring seal.

As required for the specific contents, applicable procedures will specify the use of the Alternate B port covers. In these loading procedures, the Alternate B port cover helium leakage rate testing is described. For other content loading procedures, either port cover design can be used. However, Note: Alternate B port covers, if used, require the satisfactory completion of a helium maintenance leakage rate test to confirm a leaktight seal condition for each loaded transport. Install the Alternate B port cover and perform the maintenance leakage rate test per the requirements of Section 8.1.3.3.2.

36. Decontaminate the cask. Survey the cask for surface contamination and radiation dose rates.

    Note: Ensure compliance with 10 CFR 71.87(i) and 10 CFR 71.47.

37. Remove lift yoke arm guides. Engage the cask lifting yoke to the lifting trunnions.
38. Lift the cask and position the cask rotation sockets in the rear rotation trunnions of the rear support structure. Carefully lower the cask to the horizontal transport orientation resting on the front saddle by moving the crane and/or trailer, as required, to maintain cask engagement to the rear supports.
39. Disengage the cask lifting yoke from the cask lifting trunnions and remove it from the area.
40. Install the cask tie-down strap. Install the top and bottom impact limiters.
41. Install a TID to an attachment point on the top impact limiter.
42. Install roof cross-members, close ISO container doors, and replace ISO container roof.
43. Complete radiation and contamination surveys of the external surfaces of the package and record the data. Ensure removable contamination and radiation dose rate survey results comply with the limits specified in 10 CFR 71.87(i) and (j).
44 Measure the dose rate in millirems per hour at one meter from the package surface to determine the Transport Index (TI). Indicate the TI on the Radioactive Material labels applied to the package in accordance with 49 CFR 172, Subpart E.
45. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.
46. Apply appropriate placards to the transport vehicle in accordance with 49 CFR 172, Subpart F.
47. Complete the shipping documents and provide the carrier with instructions regarding the requirements for maintaining an exclusive use shipment.

7.1.13 Procedure for Loading HEUNL Into the NAC-LWT Cask

This section describes the procedural steps required to load and prepare the NAC-LWT cask for transport with HEUNL contents. Four HEUNL containers are to be loaded into a NAC-LWT, configured as shown on Drawing No. 315-40-180, using empty HEUNL containers as spacers if not filled to capacity.

Depending on facility capabilities and/or site restrictions, filled HEUNL containers containing approximately 17 gallons may be loaded in the NAC-LWT in either the vertical or horizontal orientation using appropriate container configuration and Dry Transfer System (DTS) equipment. Alternatively, an individual empty HEUNL container may be staged at the opening of an NAC-LWT in the horizontal orientation and filled in situ prior to loading into the cask cavity. The following procedure is based on the horizontal loading of the HEUNL containers and in situ HEUNL content loading with the containers positioned at the opening in the top of the NAC-LWT cask cavity.

1. Perform a receiving survey of the cask ISO container and inspect for damage.
2. Open the front and rear ISO doors and perform a Health Physics survey of the cask and adjacent surfaces of the trailer for radiation and removable contamination per 10 CFR 20 and 49 CFR 173. If radiation or contamination levels exceed the limits of 49 CFR 173.441 or 173.443, respectively, the user/licensee shall notify the shipper, NAC, and ensure the appropriate notifications are completed.

   Note: Verify that the package nameplate displays the package identification number, in accordance with the CoC.
3. Remove the roof from the ISO container. Remove roof cross-members, if installed.
4. Remove the top impact limiter and tamper indicating device (TID), if installed.
5. Visually inspect the neutron shield tank fill, drain and level inspection plugs for signs of neutron shield fluid leakage. If leakage is detected, verify shield tank fluid level and correct, as required.
6. Remove the vent and drain valve port covers. Prior to reinstallation of the port covers, carefully inspect the valve port cover O-ring seals. If the O-rings show any damage, replace them with approved spares. Ensure that the replacement O-rings are properly installed and seated. Visually inspect the valved quick-disconnect nipples and replace them, if necessary.
7. Attach the horizontal lid removal tool to the closure lid. Remove closure lid bolts. Remove the closure lid and set it on a support that is suitable for radiological control and for maintaining the cleanliness of the closure lid. Prior to reinstallation of the lid, carefully inspect the Teflon O-ring seal in the underside of the closure lid. If the O-ring shows any damage, replace it. Remove the metallic O-ring and replace it with an approved spare. Ensure that the replacement O-ring(s) is properly installed and seated. Inspect the lid bolts and replace any that are damaged.
8. Remove any shipping dunnage as necessary and visually inspect the inner cavity for foreign material or damage. Clean all accessible surfaces, including the lid sealing surface. If required, install or verify the presence of the HEUNL container guide.
9. Install or verify the presence of the HEUNL container spacer.
10. Position an empty HEUNL container in the cask cavity for connection to the HEUNL material transfer system.
11. Fill the HEUNL container with HEUNL material.
12. Disconnect the material transfer system from the HEUNL container fill/drain and vent valves and perform a vacuum rate-of-rise test on the container valves as follows:

   a. Using a vacuum test fixture with a calibrated vacuum gauge on the face of the container, evacuate the valve annulus to a level sufficient to detect leakage at a rate of 10^{-3} ref-cm^3/s.
   b. Isolate the vacuum source and observe the vacuum gauge for the duration specified in the test procedure.
   c. The acceptance criterion for the test is no measurable rise in pressure during the minimum test time. An acceptable test assures that the valve closure verification leakage test sensitivity is achieved.

13. Install the HEUNL container lid.
14. Push the filled and assembled HEUNL container into the cask cavity to seat against the HEUNL container spacer.
15. Repeat the filling, closure, and loading process for subsequent HEUNL containers, or substitute empty HEUNL containers as spacers, seating against the previously loaded container.
16. Verify that the HEUNL container contents and loading arrangement comply with the content type, form, heat load and quantity conditions of the NAC-LWT CoC. Assure fissile material in the package is limited to a density of 7.2 g ^{235}U/L.
17. Position the closure lid in the cask using the lid match marks as guides to align the lid. Visually confirm that the closure lid is flush with the top of the cask and properly seated. Install lid bolts hand tight and remove the horizontal tool.
18. Tighten the 12 closure lid bolts to 260 ± 20 ft-lb in three passes, using the torque sequence stamped on the closure lid.
19. Evacuate the cask cavity to a vacuum pressure of less than 10 torr (13 mbar).
20. Backfill the cask cavity with helium to 0 psig (1 atmosphere, absolute), +2, -0 psi.
21. Perform the helium leakage test of the closure lid containment O-ring using a Helium Mass Spectrometer Leak Detector (He MSLD) in accordance with the requirements of Section 8.1.3.1.
22. Install the vent and drain port covers and torque the bolts to 100 ± 10 inch-pounds.
23. If an alternate port cover containment O-ring seal was replaced, perform a helium leakage test on the affected port cover using an MSLD in accordance with the requirements of Section 8.1.3.2.2.
24. If the alternate port cover containment seal was inspected and accepted for reuse, perform a gas pressure drop leakage test on the port cover as follows.
    a. Install a pressure test fixture to the port cover test port, including a calibrated pressure gauge with a minimum sensitivity of 0.25 psi.
    b. Pressurize the port cover seal annulus to 15 psig, +1, -0 psi.
    c. Isolate the gas supply and observe the pressure gauge for a minimum of five minutes.
    d. The acceptance criterion for the test is no measurable drop in pressure during the minimum test time. An acceptable test assures that the minimum assembly verification leakage test sensitivity is achieved.

25. Decontaminate the cask. Survey the cask for surface contamination and radiation dose rates and decontaminate the cask as required.

    Note: Removable contamination levels and radiation levels shall comply with 49 CFR 173.443 and 173.441, respectively.

26. Verify the correct installation of the cask tie-down strap. Install the top impact limiter and verify the correct installation of the bottom impact limiter.

27. Install a TID to one of the top impact limiter ball lock pins.

28. Replace roof cross-members if installed, and replace ISO container roof.

    Complete a Health Physics survey on the external surfaces of the package and record the results. Complete dose rate measurements at the package surface, at 1 meter from the package surface, and at 2 meters from the vertical plane of the side of the transport vehicle. The maximum dose rate at 1 meter from the package is the transport index (TI). Ensure compliance with 10 CFR 71.87(i) and observe the following criteria.

    a. If the dose rate is less than 2 mSv/h (200 mrem/hr) at all accessible points on the external surface of the package, and the TI is less than 10, the package meets the requirements of 10 CFR 71.47 (a).
    b. If the dose rate is greater than 2 mSv/h (200 mrem/hr), but is less than 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, or the TI is greater than 10, the package must be shipped as "exclusive use" and meet the requirements of 10 CFR 71.47 (b), (c) and (d). If the dose rate and shipping requirements of 10 CFR 71.47 (b), (1), (2), (3) and (4) cannot be met, the package cannot be shipped.
    c. If the dose rate is > 10 mSv/h (1000 mrem/hr) at any point on the external surface of the package, the package exceeds the limits of 10 CFR 71.47 and cannot be shipped.

29. Determine the appropriate Criticality Safety Index (CSI) assigned to the package contents in accordance with the CoC, and indicate the correct CSI on the Fissile Material label applied to the package per 49 CFR 172, Subpart E.

30. Complete the shipping documents, carrier instructions (as required), and apply appropriate placards and labels.

8.1.4.4 HEUNL Container

The boundary of the HEUNL container shall be qualified by hydrostatic testing prior to first use following fabrication, and periodically during service (after every 50 fill/drain cycles), or after fill/drain and/or vent valves are rebuilt or replaced. A hydrostatic test will be performed in accordance with the "ASME Boiler and Pressure Vessel Code," Section III, Subsection NB, Article NB-6000, to 140 +10/-0 psig (1.25 × 112 psig = 140 psig). The test requirements and acceptance criteria for both tests are described below.

The HEUNL container is hydrostatically tested using demineralized water. The test is conducted with the fill/drain and vent valves installed. During these two pressure tests (conducted alternately on each valve while a test fixture is connected to the other for access to the cavity), the hydrostatic pressure shall be maintained for a minimum of 10 minutes followed by an inspection of the container to detect any visual or other evidence of leakage. Any evidence of leakage of the container is cause for rejection. Following the visual inspection, the container pressure is vented.

Following the hydrostatic tests, the HEUNL container is drained, dried and made ready for post-test inspections. The container body and valves are visually inspected.

Additionally, prior to the initial first use fabrication acceptance test all accessible structural welds of the HEUNL container body. The structural welds shall be examined by dye-penetrant examination (PT) in accordance with ASME Code, Section V, Article 6, with acceptance criteria in accordance with ASME Code, Section III, Subsection NB, Article NB-5350.
Any evidence of cracking, permanent deformation, or exceeding of material yield strength is cause for rejection.

8.1.4.5 Miscellaneous

The cask impact limiter structures contain a two-part, aluminum honeycomb that is fabricated to have dynamic crush strengths of 3,500 psi. (plus 5 percent, minus 10 percent) and 250 psi (plus 10 percent, minus 10 percent), respectively. Sample lots of honeycomb material are subjected to dynamic crush testing to verify the crush strength of the impact limiter material. A dynamic crush strength of a sample outside of the allowable variation is cause for rejection of the batch lot of honeycomb material.

8.1.5 Tests for Shielding Integrity

A gamma scan inspection of all steel and lead shielding is conducted in order to verify shielding integrity. This inspection is performed on the cask body, including the cask bottom.

The test is conducted by continuous scanning or probing over 100 percent of all accessible surfaces, using a 3-inch detector and a ^{60}Co source of sufficient strength to produce a count rate that equals or exceeds three times the background count rate.

Scan path spacing is 2.5 inches. Scan speed is 4.5 feet-per-minute or less. All probing is on a 2-inch grid pattern (when using a 3-inch detector) and the count time is a minimum of one minute.

Acceptance is based on a lead and steel mock-up, where the material thicknesses are equivalent to the minimum thicknesses specified by the drawings. The lead and steel mock-up is produced using the same pouring technique as that approved for the cask.

Any area that produces a count rate over that established by the mock-up is considered rejected and must be corrected and retested prior to use.

Test equipment is checked before and after each use to ensure that shield test results are accurate.

8.1.6 Thermal Acceptance Tests

8.1.6.1 Thermal Test

A heat transfer acceptance test is conducted to test the integrity of the lead/stainless steel interface and to establish the heat rejection capability of the cask. The test is conducted with the neutron shield tank full[1] and the pressurized water reactor (PWR) basket located in the dry cask cavity.

The cask is internally heated at a rate of 8,500 BTU per hour (± 1,000 BTU per hour). A minimum of 12 internal and 12 external temperatures on the cask are measured with thermocouples. A test closure lid is used to allow penetrations for electric heaters and thermocouples. The steady state heat rate, transient cask temperatures, and ambient temperature are recorded. The test is conducted with the cask 3 feet (approximately) above the ground, horizontal and in still air.

8.1.6.2 Retest

If any equipment should fail during the test, such that the test must be aborted, the test is repeated.

8.1.6.3 Heat Source

The heat source for the thermal test is an electrical heater (cal-rod type) with an active length of 144 to 150 inches and is capable of generating at least 2.5 kilowatts.

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[1] The neutron shield tank is filled with a liquid consisting of 58 weight percent ethylene glycol, 39 weight percent demineralized water and 3 weight percent potassium tetraborate ($K_2B_4O_7$).

8.2 Maintenance Program

Each NAC-LWT cask is subjected to a series of tests and inspections prior to each loaded shipment and annually, as shown in the Maintenance Program Schedule (Table 8.2-1).

Prior to each loaded transport, the metallic O-rings of the closure lid and Alternate B port covers, if used, are replaced. The O-ring seals of the alternate port covers are inspected and replaced as necessary. The cask cavity, trunnions, and all removable components (i.e., closure lid, port covers, attachment bolts, impact limiters, etc.) are visually inspected for damage. Following loading, the closure lid and port covers are installed and the bolting torqued. Leakage rate tests are performed on the closure lid and port covers as detailed in the cask loading procedures of Chapter 7.1.

The completion of the annual maintenance and test program is required for each NAC-LWT cask while it is in service. The completion of the annual maintenance is documented on an annual inspection certification document. Each NAC-LWT cask must have a current annual certification before it can be used. The required annual cask maintenance test program is performed during or before the calendar month in which the annual program is due, but it is required to be performed no later than 30 days following the due date. During periods when the cask is not in use, the annual maintenance program may be deferred provided that the annual maintenance is completed and documented prior to the cask's next use.

For NAC-LWT casks to be used to transport TPBAR contents, a one-time post-fabrication hydrostatic test of the cask containment boundary, including Alternate B port covers, shall be performed to a pressure of 450 + 15/-0 psig.

Helium leakage rate testing to the leaktight criteria of ANSI N14.5-1997 is performed on the closure lid, and alternate and Alternate B port cover containment seals.

The annual maintenance program certification documentation shall specifically identify that a NAC-LWT packaging has been qualified by testing for TPBAR contents.

Engineering approval is required prior to making any repairs of damaged areas or areas that need refurbishing as a result of normal wear and tear. All such repairs shall be fully documented in accordance with NAC's approved Quality Assurance program. The replacement of valves, fittings, seals, thread fasteners, or use of calibrated pressure gauges are considered normal maintenance and do not require engineering approval.

Testing of the cask shielding and heat rejection capabilities is conducted during original packaging acceptance testing. The structures that provide shielding and heat rejection are passive and do not require verification during routine use of the package. Consequently, the efficiency of these systems is not tested during the annual maintenance program. Radiation surveys conducted at the time of cask loading provide verification of continued shielding effectiveness.

Testing of the neutron absorber material utilized in TRIGA poisoned basket modules are conducted prior to fabrication of the basket modules. The neutron absorber material is in the form of borated stainless steel sheets that are visually inspected for wear or damage prior to each use, and do not require routine maintenance.

For every loaded shipment, each HEUNL container shall be visually inspected for damage and dimensionally gauged for axial deformation prior to filling, by passing a 44.78 (+0/-0.010)-inch GO-gauge over the container. Failure to pass freely through the gauge shall result in rejection of that container. When filled, HEUNL container fill/drain and vent valves shall be leak tested for closure verification prior to installation of the container lid. The acceptance criterion is no measurable rise in pressure during the duration of a vacuum rate-of-rise test measured with the sensitivity to detect leakage at a rate of 10^{-3} ref-cm^3/s. If replacement of the fill/drain and/or vent valves is warranted, and after every 50 fill/drain cycles, the hydrostatic testing described in Section 8.1.4.4 shall be performed to re-qualify the boundary prior to returning the HEUNL container to service.

8.2.1 Authorized Repairs

Repairs are authorized to correct cracks and blemishes resulting from normal wear and tear of the components of the NAC-LWT packaging. Performance of authorized repairs will result in an as-licensed configuration. The specific weld repair procedure for the impact limiter attachment lugs is described in Section 8.2.1.1.

8.2.1.1 Impact Limiter Attachment Lug Repairs

Impact limiter lugs shall be visually examined prior to each transport to ensure that the impact limiters can be attached to the NAC-LWT cask body in accordance with the Transport Cask Assembly drawings presented in Chapter 1. During annual NAC-LWT packaging maintenance, the impact limiter attachment lugs and the welds sealing the impact limiter shell to the lugs are visually examined with acceptance criteria in accordance with ANSI/AWS Code D1.2, Paragraph 8.8.1. If defects in the impact limiter shell-to-lug welds or in the lug base material are identified, the weld is repaired in accordance with the applicable License Drawing requirements.

Defects in the shell-to-lug weld are removed by grinding, and the shell is rewelded to the lug. If the lug base material has a defect or is broken in two pieces, the lug base material is prepared to allow completion of a full-penetration weld. The weld repairs shall be performed by qualified welders utilizing approved welding procedures prepared, approved and qualified in accordance with ASME Code, Section IX, or ANSI/AWS D1.2. Approved lug repair welding procedures will validate that the axial load path minimum yield strength and ultimate strength of the completed repair will be 10.0 ksi and 20.0 ksi , respectively, or greater, and that the maximum temperature in the base lug material local (within 0.5 inch) to the weld repaired is maintained less than 350°F during the welding process. Following shell-to-lug weld repairs or completion of the full-penetration welding of the lug base material, the weld shall be examined by liquid penetrant examination in accordance with ASME Code, Section V, Article 6, or ANSI/AWS D1.2. Weld acceptance criteria for the liquid penetrant examination shall be in accordance with the ASME Code, Section VIII, Division 1, Appendix 8, or ANSI/AWS D1.2, Paragraph 6.17, as applicable.

Inspection and weld repair documentation shall be maintained as part of the maintenance records for the specific NAC-LWT packaging.

Table 8.2-1 Maintenance Program Schedule

Cask Cavity (Including Port Cover and Lid Seals)	
Annually	Visual Inspection Lid and Port Cover Seal Replacement Periodic Helium Leak Tests (per Section 8.1.3)
Valve Port Covers	
Each Loaded Shipment	Visual Inspection Air Pressure Drop Test at 15 +1/-0 psig (Alternate port covers) Maintenance Helium Leakage Testing (Alternate B port covers) Seal Replacement as Necessary[1]
Drain Line Gasket	
Each Shipment	Seal Replacement as Necessary
Annually	Seal Replacement
Water Jacket and Expansion Tank	
Annually	Visual Inspection Check Fluid Level, Specific Gravity, and Boron Concentration[2]
Each Shipment	Visually Inspect Fill, Drain and Inspection Port Plugs for Leakage
Cask Lid Bolts	
Each Shipment	Visually Inspect for Damage and Replace, as required.
Long Term Maintenance	Bolt replacement upon reaching 20-year life or 550 operational cycles.

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[1] Helium leak testing (per Section 8.1.3.2.2) is required following replacement of alternate port cover containment (i.e., face) O-ring seals. For Alternate B port covers, seal replacement and leak testing are required for each shipment per the requirements specified in the Operating Procedures in Chapter 7 and Section 8.1.3.3.2.

[2] The neutron shield fluid must be verified to contain greater than 1.0 wt % boron and the specific gravity must be such that the solution does not freeze at temperatures above -40°F.

Table 8.2-1 Maintenance Program Schedule (continued)

Water Jacket Relief Valve	
Annually	Replace With New Pre-set Valve, or Verify Opening and Reseating Pressure (Allowable variation is ± 10 psig of Nominal Valve Opening Pressure, 165 psig)
Fasteners, Valved Nipples, Washers, Reusable O-rings, and Helicoils	
Each Shipment	Inspect and Replace as necessary
Lid and Alternate B Port Cover Metallic O-rings	
Each Loaded Shipment	Replace and perform helium leakage rate testing to the criteria specified in Section 8.1.3.
HEUNL Container	
Each Loaded Shipment	Visually inspect HEUNL container for damage and perform dimensional gauging in accordance with Section 8.2 prior to filling. Perform rate-of-rise leakage testing for fill/drain and vent valve closure verification in accordance with Section 8.2 when filled.
Every 50 Fill/Drain Cycles or Upon Repair/Replacement of Fill and Drain Valves	Perform hydrostatic testing in accordance with Section 8.1.4.4.