ATTACHMENT 3

M170117

Responses to the NRC RAIs for the Model No. 2000 Transportation Package

Non-Proprietary Information – Class I (Public)

IMPORTANT NOTICE

This is a non-proprietary version of M170117 Attachment 2, which has the proprietary information removed. Portions of the document that have been removed are indicated by white space with an open and closed bracket as shown here [[ ]].

General Information Review

1.1 Clarify the maximum U-235 equivalent mass authorized for transport.

Although Section 1.2.2.3 states the maximum amount of special nuclear material for transport is 430 grams U-235 equivalent mass, 500 grams U-235 equivalent mass is specified both in the Section 7.2.2.2 title and text. The applicant needs to revise the SAR pages which incorrectly specify the allowable U-235 equivalent mass.

This information is necessary to satisfy the requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) 71.33(a)(5).

GEH Response

At this time, GEH is no longer pursuing Special Nuclear Material (SNM) as a content. Revision 1 of NEDE-33866P will remove such content including SNM from Sections 1.2.2.3 and 7.2.2.2; therefore, RAI 1.1 is no longer applicable.

Structural Review

2.1 Provide the following information with respect to the material basket stress analysis for the NCT end drop:

a) the maximum induced bending and shear stresses in the basket,

b) the minimum margin of safety in the basket, and

c) the technical justification(s) to the assumption of no axial load.

This information is needed to verify compliance with 10 CFR 71.71(c)(7).

GEH Response

The material basket is loaded by inertial forces during an end drop accident. Depending on the orientation of the outer cask when dropped, the basket contents will either load the material basket or the lid of the high performance insert (HPI). There is a washer welded to the bottom of the basket pipes that holds the rod holders. Nothing prevents the rod holders from exiting the top of the material basket. If the outer cask is dropped while in the upright position, the material basket will be loaded by the contents. The worst-case condition of upright end drop is evaluated. The inertial loading will load the pipe bundle in compression. There is no bending or shear stress present. For this evaluation, all 18 pipes are loaded.

a) Stresses

$\sigma_{\text{membrane}} = \frac{P}{A} = 837$ psi compression

$\sigma_{\text{bending}} = 0$ psi

$\tau_{\text{shear}} = 0$ psi

where	$P = W \times G = 4913.5$ lbs	Inertial load on 18 pipe sections
	$W = 317$ lbs	Basket plus contents weight (NEDE-33866P Revision 0, Table 2.1-3)
	$G = 15.5$ G	Normal conditions of transport (NCT) end drop acceleration (NEDE-33866P Revision 0, Table 2.6.7-1)
	$A = 3.91 \times 1.5 = 5.87$ in^2	Cross section area of 18 pipes (12 pipe area x 1.5) (NEDE-33866P Revision 0, Table 2.6.7-18)
	$S_y = 16900$ psi	Yield Strength, 316 stainless steel, 800°F (NEDE-33866P Revision 0, Table 2.2-1)

b) Minimum Margin of Safety

The minimum margin of safety for the NCT end drop case is:

$$MS = \frac{S_y}{\sigma_m} - 1 = \frac{16900}{837} - 1 = +19.2$$

(NEDE-33866P Revision 0, Table 2.1-2, Bearing Loads: Service Level A)

c) Technical Justification for No Axial Load

The material basket is loaded by inertial forces during an end drop accident. Depending on the orientation of the outer cask when dropped, the basket contents will either load the material basket or the top plug of the HPI. There is a washer welded to the bottom of the basket pipes that holds the rod holders. Nothing prevents the ends of the rod holders from exiting the top of the material basket and contacting the HPI top plug. If the outer cask is dropped while in the upright position, the material basket will be loaded by the contents. The inertial loading will load the pipe bundle in compression.

During an end drop, the inertia load on the pipe columns from the basket and contents load the material basket in a manner which does not compromise its source spacing function. However, the side drop does load the material basket in a manner requiring analysis with respect to source spacing. During the side drop the steel alignment disks provide a close fit with the high performance insert inner shell, which distributes the inertial load on the basket beam segments along the length of the assembly. Therefore, the side drop is considered the limiting impact orientation to demonstrate that the material basket performs its safety function of source spacing. See NEDE-33866P Revision 0, Sections 2.6.7.3 and 2.7.1.3, for the results of the material basket evaluation for side drop NCT and hypothetical accident condition (HAC) respectively.

2.2 Provide the following information with respect to the material basket stress analysis for the HAC end drop:

a) the maximum induced bending and shear stresses in the basket,

b) the minimum margin of safety in the basket,

c) technical assumptions (e.g., no axial load in the basket, etc.) made for the material basket stress analysis, and

d) buckling analysis and its results for the elastic stability of the basket.

This information is needed to verify compliance with 10 CFR 71.73(c)(3).

GEH Response

The material basket is loaded by inertial forces during an end drop accident. Depending on the orientation of the outer cask when dropped, the basket contents will either load the material basket or the lid of the high performance insert (HPI). There is a washer welded to the bottom of the basket pipes that holds the rod holders. Nothing prevents the rod holders from exiting the top of the material basket. If the outer cask is dropped while in the upright position, the material basket will be loaded by the contents. The worst-case condition of upright end drop is evaluated. The inertial loading will load the pipe bundle in compression. There is no bending or shear stress present. For this evaluation, all 18 pipes are loaded.

a) Stresses

$\sigma_{\text{membrane}} = \frac{P}{A} = 8505.5$ psi compression

$\sigma_{\text{bending}} = 0$ psi

$\tau_{\text{shear}} = 0$ psi

where $P = W \times G = 49927.5$ lbs — Inertial load on 18 pipe sections

$W = 317$ lbs — Basket plus contents weight

$G = 157.5$ G — Hypothetical accident condition (HAC) end drop acceleration (NEDE-33866P Revision 0, Table 2.7.1-1.)

$A = 3.91 \times 1.5 = 5.87$ in^2 — Cross section area of 18 pipes (12 pipe area x 1.5)

b) Minimum Margin of Safety

Per NEDE-33866P Revision 0, Table 2.1-2, except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D service limits are specified.

c) Technical Assumptions

See the GEH response to RAI 2.1.c).

d) Buckling Analysis – Elastic Stability of Basket During End Drop

The basket elastic stability is evaluated at HAC end drop conditions. The basket pipes are modeled as a column with pinned ends. The bottom third of the 18 pipe bundle is located between the HPI bottom and the material package center of gravity and is therefore evaluated using the Euler equation for buckling of a column with pinned ends:

$$P_{cr} = \frac{\pi^2 E I_{cc}}{L^2} = 5.553 \times 10^7 \text{ lbs}$$

where $E = 24.1 \times 10^6$ psi Modulus of 316 stainless steel, 800°F

(NEDE-33866P Revision 0, Table 2.2-2)

$L = 14.89$ in Length of lower 3rd of basket between alignment rings

(NEDE-33866P Revision 0, Drawing 001N1824)

$I_{cc} = 51.76\ in^4$ Moment of inertia (18 pipes)

For the HAC end drop elastic stability evaluation, the moment of inertia for the 18 pipes is determined from NEDE-33866P Revision 0, Table 2.6.7-18, as follows:

Number of Pipes, N	I_c (in^4)	$I_{cc} = N \times I_c$ (in^4)
3	4.40	13.20
4	2.34	9.36
4	1.66	6.64
4	2.34	9.36
3	4.40	13.20
18		51.76

Comparing the critical load to the load applied to the 18-pipe basket during the HAC end drop, the factor of safety is:

$$FS = \frac{P_{cr}}{P} = \frac{5.553x10^7}{49927.5} = +1112.2$$

Thermal Review

3.1 Provide the data source for the Aluminum Honeycomb thermal conductivity and emissivity values used in the normal conditions of transport (NCT) and hypothetical accident conditions (HAC) thermal analyses.

The applicant listed the thermal properties of Aluminum Honeycomb in Table 3.2.1-1 of NEDE-33866P (Rev. 0), based on References 3-4 (Hexcel Corporation) and 3-7 (Siegel and Howell), for the NCT and HAC thermal analyses. Staff notes the Aluminum Honeycomb thermal conductivity listed in Table 3.2.1-1 is low compared with solid aluminum. In addition, both the thermal conductivity and emissivity values in Table 3.2.1-1 for Aluminum Honeycomb are not listed in References 3-4 and 3-7 of NEDE-33866P (Rev. 0). The applicant needs to provide the source from which the Aluminum Honeycomb thermal conductivity and emissivity values were obtained as well as justify that the value is acceptable.

This information is required by the staff to access compliance with 10 CFR 71.33(a)(5)(v), 10 CFR 71.71 and 10 CFR 71.73.

GEH Response

By the nature of the design, thin foil surrounding entrapped air, aluminum honeycomb will have a lower thermal conductivity than solid aluminum and is therefore a less efficient conductor of heat. This has been accounted for in the thermal analysis.

The following discussion provides the basis for the thermal conductivity values listed in NEDE-33866P Revision 0 Table 3.2.1-1 and their applicability to the aluminum honeycomb. From References 3.1-1 and 3.1-2, the aluminum honeycomb design is specified as .125 - 5052 - .002: cell size is 0.125 inches, material is aluminum alloy 5052, and the nominal reference foil thickness is 0.002 inches.

The thermal conductivity for this design is determined from Reference 3.1-3, pages 20 and 26. From the table on page 26 of Reference 3.1-3, the nominal density of 1/8 – 5052 – .002 is 8.1 lbs/ft^3. From page 20 of Reference 3.1-3, the thermal conductivity for a density of 8.0 lbs/ft^3 at 75°F is 103 BTU-in/hr-ft^2-°F = 0.715 BTU/hr-in-°F.

Because the density associated with the 1/8 – 5052 - .002 aluminum honeycomb is close to 8.0 lb/ft^3, the thermal conductivity value of 0.715 BTU/hr-in-°F at 75°F is used. To adjust for mean temperatures other than 75°F, multiply the thermal conductivity at 75°F by Q obtained from the bottom figure on page 20 of Reference 3.1-3.

Section 3 of Reference 3-7 cited in NEDE-33866P, Revision 0 incorrectly identifies the second edition as the source for the aluminum honeycomb emissivity. The third edition is correct. From Reference 3.1-4, Appendix D, page 1039, the emissivity for highly oxidized aluminum is as follows.

Temperature (°F)	Emissivity
200	0.20
1000	0.33

The value for highly oxidized aluminum is applicable because the aluminum honeycombs have been installed in the Model 2000 cask overpack for over 25 years. From NEDE-33866P Revision 0, Table 3.5.1-1, the temperature of the honeycomb impact limiters for a decay heat of 1500 W is 272°F. Because GEH is not pursuing Configuration 2 (3000 W decay heat) for cobalt (Co) isotope transport at this time, the 1500 W decay heat temperature is applicable. Assuming emissivity is linear with temperature, the relationship is $\varepsilon = 0.0001625 \times T$ (°F) + 0.1675. The small value for the slope indicates small sensitivity to temperature changes. For 272°F, the corresponding emissivity obtained from this linear relationship is 0.2117, which is negligibly larger than the 0.20 used in the analysis. From NEDE-33866P Revision 0, pages 3-28 and 3-29, thermal radiation is treated as a convection boundary condition:

$$h_r = \varepsilon\sigma(T_s^2 + T_\infty^2)(T_s + T_\infty)$$

where:

ε = emissivity = 0.20 at 200°F (659.67 R) and 0.2117 at 272°F (731.67 R)

σ = Stefan-Boltzmann constant = 1.19E-11 BTU/hr-in^2-R^4

T_s = surface temperature (R)

T_∞ = temperature of surroundings = 75°F (534.67 R)

The following table summarizes h_r at 200°F and 272°F:

Temperature of Surface (°F)	Emissivity	Thermal Radiation Coefficient (h_r)
200	0.20	0.00205
272	0.2117	0.00262

Both values above for the honeycomb material are in close agreement with NEDE-33866P Revision 0, Figure 3.3-7, the h_r plot for all surfaces. Therefore, the use of 0.20 for the emissivity of highly oxidized aluminum at 200°F is acceptable for the thermal evaluation of the GE-2000 transport container with the HPI at 1500 W decay heat. As stated previously, Configuration 2 (3000 W decay heat) is no longer being pursued by GEH at this time.

References

3.1-1 101E8719, Revision 13, Model 2000 Cask Overpack, Serial Number 2001.

3.1-2 105E9521, Revision 6, Model 2000 Cask Overpack, All Serial Numbers Except 2001.

3.1-3 "HexWeb® Honeycomb Attributes and Properties," Hexcel Corporation, Copyright 2016.

3.1-4 Robert Siegel and John R. Howell, "Thermal Radiation Heat Transfer," Third Edition, Hemisphere Publishing Corporation, 1992.

Containment Review

4.1 Provide the allowable Configuration 1 containment O-ring seal temperature limits.

The applicant stated in Section 1.2.1.1 of NEDE-33866P (Rev. 0) that ethylene propylene diene monomer (EPDM) seals are used for the Configuration 1 cask lid, vent port plug, drain port plug and test port plug, and displayed the following allowable temperature limits in Table 3.5.1-3 (NCT) and Table 3.5.1-5 (HAC) for these locations: lid seal (400°F), drain port seal (612°F), vent port seal (612°F) and test port seal (612°F). The applicant needs to clarify why the allowable temperature limits are different at these locations even though the same EPDM material is used.

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

GEH Response

At this time, GEH is no longer pursuing the Configuration 2 option (3000 W decay heat). Revision 1 of NEDE-33866P will remove such content; therefore, this response does not address the 3000 W decay heat option.

For use with 1500 W decay heat, the cask seal and O-rings are made from EPDM material. EPDM has been shown to experience no thermal degradation up to 400°F as discussed in Section 4.4 of NEDE-33866P Revision 0. The normal conditions of transport (NCT) temperatures for 1500 W decay heat at each location are presented in Table 4.1-1, taken from Table 3.5.1-3 of NEDE-33866P Revision 0. The temperatures at all seal and O-ring locations are below the allowable temperature of the EPDM material. Therefore, the EPDM material will perform acceptably during routine and normal conditions of transport for all sealed locations.

Table 4.1-1: Seal and O-Ring Temperatures for NCT, 1500 W Decay Heat

Location	NCT Temperature (°F)
Cask Lid Seal	317
Cask Drain Port (Bottom)	279
Cask Test Port (Top)	314
Cask Vent Port (Lid)	323

The cask seal and port O-ring temperatures for hypothetical accident conditions (HAC) and 1500 W decay heat are presented in Table 4.1-2, taken from Table 3.5.1-5 of NEDE-33866P Revision 0. The cask seal and cask vent port temperatures are within the allowable temperature for EPDM. The drain port and test port exceed the seal material allowable temperature by 137°F and 115°F, respectively, and therefore the EPDM O-rings will degrade at these ports. This is considered acceptable because 1) the duration of HAC maximum temperatures at these ports is short, < 1 hour per Table 3.5.1-4 of NEDE-33866P Revision 0, resulting in minor material degradation; and 2) the port O-rings and port covers are outside the containment boundary as illustrated in Figure 4.1.3-1 of NEDE-33866P Revision 0, Cask Containment Boundary.

Table 4.1-2: Seal and O-Ring Temperatures for HAC, 1500 W Decay Heat

Location	HAC Temperature (°F)
Cask Lid Seal	389
Cask Drain Port (Bottom)	537
Cask Test Port (Top)	515
Cask Vent Port (Lid)	392

In summary, the cask seal and port EPDM O-ring material was selected based on maximum NCT temperatures below EPDM allowable temperature to ensure thermal degradation does not occur during routine or normal conditions of transport. With regard to containment, the cask port containment boundary is the pipe plug. Therefore, the slight degradation of the EPDM O-rings at the drain and test ports for HAC and 1500 W decay heat will have no effect on containment. To demonstrate containment safety, the pipe plug was demonstrated to remain leak tight at conditions in excess of 1500 W decay heat maximum HAC temperatures. The cask lid seal has been demonstrated to maintain leak tightness at HAC conditions and 1500 W decay heat.

Section 1.2.1.1 of NEDE-33866P Revision 0 will be updated to remove the current EPDM allowable temperature discrepancy, and an explanation for the acceptability of EPDM sealing material performance at HAC and 1500 W decay heat will be added.

4.2 Provide the allowable Configuration 2 containment O-ring seal temperature limits.

The applicant stated in Section 3.2.2 of NEDE-33866P (Rev. 0) that [[ ]] seals are used at the cask lid, vent port plug, drain port plug and test port plug of Configuration 2, and displayed the following allowable temperature limits in Table 3.1.3-2 (NCT) and Table 3.1.3-3 (HAC) for these locations: lid seal (508°F), drain port seal (612°F), vent port seal (612°F) and test port (612°F). The applicant needs to clarify why the allowable temperature limits are different at these locations even though the same type of [[ ]] seal is used.

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

GEH Response

At this time, GEH is no longer pursuing the Configuration 2 option (3000 W decay heat). Revision 1 of NEDE-33866P will remove such content, and therefore RAI 4.2 regarding allowable Configuration 2 O-ring seal temperature limits is no longer applicable.

4.3 Provide test conditions and results on permeation of the new [[ ]] seal material.

Permeation can cause problems when demonstrating that a system is leaktight. The degree of permeation is affected by factors such as seal material, seal surface area, time and temperature. If the new [[ ]] seal material is permeable to helium, the staff needs to determine if the applicant can accurately differentiate helium detection caused by a leaking [[ ]] seal and helium permeating from an intact [[ ]] seal to the leaktight criterion on a repeatable basis. The applicant needs to provide the test conditions and results from the acceptance testing.

This information is needed to determine compliance with 10 CFR 71.51(a)(1), and 10 CFR 71.87(c).

GEH Response

The new [[ ]] seal material is introduced for the GE-2000/high pressure insert (HPI) Configuration 2 option (3000 W decay heat). At this time, GEH is no longer pursuing the Configuration 2 option. Revision 1 of NEDE-33866P will remove such content, and therefore RAI 4.3 regarding test conditions and results of the new [[ ]] is no longer applicable.

Shielding Review

5.1 Justify the gamma and neutron source term strength.

Typical spent fuel source terms for gammas increase linearly with burnup and to the fourth power for neutrons as discussed in NUREG/CR-6802. However, neither the gamma source strength in Table 5.2-2 of the SAR nor the neutron source strength in Table 5.2-6 of the SAR follow these relationships. The applicant needs to justify this atypical source term strength increase with increasing burnup.

This information is needed to verify compliance with 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

GEH Response

At this time, GEH is no longer pursuing irradiated fuel as a content. Revision 1 of NEDE-33866P will remove such content, including Table 5.2-2 and Table 5.2-6; therefore, RAI 5.1 regarding the spent fuel source term is no longer applicable.

5.2 Discuss how fuel assemblies other than GE 10x10 meet both thermal and external dose rate regulations.

Chapter 1 of the SAR does not limit what kind of irradiated fuel will be shipped. All decay heat and external dose rate evaluations are based on source terms from GE 10x10 fuel. The applicant needs either to discuss how GE 10x10 fuel assemblies provide bounding radiological and decay heat source terms, or to provide additional information explaining how non-GE 10x10 fuel assemblies meet thermal and external dose rate regulations given the different source term they would produce.

This information is needed to verify compliance with 10 CFR 71.33(b)(1), 10 CFR 71.33(b)(7), 10 CFR 71.47(b), and 10 CFR 71.51(a)(2).

GEH Response

At this time, GEH is no longer pursuing irradiated fuel as a content. Revision 1 of NEDE-33866P will remove such content; therefore, RAI 5.2 regarding how fuel assemblies other than GE 10x10 meet both thermal and dose rate regulations is no longer applicable.

5.3 Provide neutron emitting nuclide limits for the irradiated hardware and byproduct contents to be shipped in the GE-2000.

Section 7.5.2 states that “any neutron emitting radionuclides are limited to trace amounts, strictly from surface contamination of the hardware or byproducts are permitted for shipment.” Since “trace amounts” is subjective, a quantitative limit should be specified. The staff also notes that many nuclides in Table 5.5-7 of the SAR can either emit neutrons directly or by alpha-n reactions. These include, but are not necessarily limited to Np-237, Cm-242, Cm-244, Am-241, Pu-238, Pu-239, and Pu-240. The applicant needs to provide both a limit for all neutron emitters in this table and a justification for this limit.

This information is needed to verify compliance with 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

GEH Response

The term “trace amounts” refers to the buildup of “crud” deposits on irradiated hardware. Specific limits for alpha and neutron emitters are already covered by the thermal limits imposed on the GE-2000 shipping cask and subsequent Curie (Ci) limits. Table 5.5-30 of NEDE-33866P lists the isotope decay heat data used to calculate the total thermal content as required by the loading plan in Section 7.5.2.

Section 6.1.1 of NUREG/CR-6487 (Reference 5.3-1) states that the Ci content for crud build-up is 1,254x10^{-6} Ci/cm^2 for boiling water reactor (BWR) rods. This limit can be conservatively applied to any hardware within a BWR or pressurized water reactor.

As shown in Tables 7-3 and 7-4 of NAS-NS-3199 (Reference 5.3-2), the alpha and neutron emitters contribute very little to the total dose as compared to the gamma emitters. Tables 7-3 and 7-4 of Reference 5.3-2 provide specific activity concentrations for Cm-242 and Pu-241, and lump the remaining transuranic (TRU) isotopes together because their activity concentrations are very low. The alpha and neutron emitters do have a larger contribution to the total thermal limit, as shown in Table 5.5-30 of NEDE-33866P. However, given that the total mass of the crud is small, the crud contributes little to the total thermal content.

To ensure that the additional conservatisms which account for the Ci and thermal effects of the alpha and neutron emitters are applied in the loading plan, GEH will strengthen the wording of NEDE-33866P Revision 1 Section 7.5.2 to include this calculational requirement. This update is consistent with the update requirements included in the GEH response to RAI 7.3.

References

5.3-1 NUREG/CR-6487, “Containment Analysis for Type B Packages Used to Transport Various Contents,” U.S. Nuclear Regulatory Commission, November 1996.

5.3-2 NAS-NS-3119, “Radiochemistry in Nuclear Power Reactors,” National Academy of Sciences, 1996.

5.4 Discuss the discrepancy between SAR Section 1.2.2.3 and SAR Section 5.5.3 regarding the allowable amount of Co-60 per rod [[ ]].

The content limit for the Co-60 isotope rods in SAR Section 1.2.2.3 differs from that stated in SAR Section 5.5.3. Section 1.2.2.3 limits the Co-60 rod [[ ]] to 17,000 Ci per rod [[ ]] within a single shipment. Section 5.5.3 (starting on page 5-48) has this same limit but the unit is per inch. Since the shielding analysis supports the per inch limit, staff intends to condition the CoC to reflect this unless the applicant provides information stating this is not the intended limit. If the per inch limit is not the intended limit, the applicant must provide justification for the 17,000 Ci per rod [[ ]] limit. Whichever limit is applicable, the applicant must reconcile the descriptions in SAR Sections 1.2.2.3 and SAR Section 5.5.3.

This information is needed to verify compliance with 10 CFR 71.33(b)(1), 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

GEH Response

The Co-60 activity limit as indicated in Item 3.c of Section 1.2.2.3 in NEDE-33866P is incorrect. The limit should be based on Ci per inch. Section 1.2.2.3 will be corrected to coincide with the Ci per inch limit as used in the supporting Chapter 5 shielding analysis.

5.5 Justify that Configuration 1 (up to 1500 Watts) sources not requiring the material basket still meet NCT dose rate limits considering the possibility of reconfiguration.

Table 1.2-1 of the SAR states that the contents limited to 1500 Watts decay heat do not require the material basket in Configuration 1. Without the material basket, or other shoring mechanisms, it is possible that the content could reconfigure during NCT. The applicant performed external dose rate evaluations for both irradiated fuel and Co-60 [[ ]] using line sources. Although the shielding evaluations are performed for Configuration 2, which allows up to 3000 Watts, the staff needs additional information demonstrating that, under plausible NCT reconfiguration, the concentrated 1500 Watt source doesn't exceed NCT dose rate limits. The applicant should either explain why the contents cannot reconfigure, provide analyses demonstrating that the contents cannot reconfigure, or provide analyses showing that the maximum reconfiguration would still not exceed regulatory external dose rate limits. The applicant could also justify if current conservative assumptions, e.g.; neglecting self-shielding, sufficiently compensate for this possibility. Alternatively, the applicant needs to discuss how these sources will be shored under NCT if they are not required to be shipped in the material basket.

This information is needed to verify compliance with 10 CFR 71.47(b).

GEH Response

The material basket is required for normal conditions of transport (NCT) shipments. GEH is no longer pursuing the 3000 W limit (Configuration 2). Thus, there will only be one configuration option. Table 1.2-1 of NEDE-33866P will be revised or deleted, and the text of Section 1.2.2.3 will be adjusted to reflect this change.

5.6 Justify that the irradiated fuel content will meet the package external dose rate regulatory limits considering the burnup profile.

Section 5.3.1.1 of the SAR states that the irradiated fuel content is a single 10-inch line source with the photon and neutron sources uniformly distributed. The applicant needs to discuss how they account for the irradiated fuel burnup profile. For instance, if the fuel is qualified for shipment based on average assembly burnup, some segment burnups could be much higher than the average burnup. The variation in fuel segment burnup will produce variations in the source terms for both gamma and neutron. NUREG/CR-6802 points out that the gamma source of spent fuel is linearly proportional to the fuel burnup and the neutron source is proportional to the fourth power of fuel burnup. In addition, the potential exists for segments to be aligned such that higher burnup sections are loaded adjacent to one another maximizing burnup and placing the package in an unanalyzed condition. The applicant needs to discuss how fuel qualified for loading is classified, i.e., by the maximum local burnup or the assembly average burnup. If the assembly average burnup is used, the applicant needs to discuss how the package still meets regulator dose rate limits by either providing an analysis or demonstrating that conservative assumptions employed within the evaluation, are enough to bound the uncertainty of the burnup.

This information is needed to verify compliance with 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

GEH Response

At this time, GEH is no longer pursuing irradiated fuel as a content. Revision 1 of NEDE-33866P will remove such content; therefore, RAI 5.6 regarding justification that irradiated fuel content will meet package external dose rate regulatory limits is no longer applicable.

Criticality Review

6.1 Provide the chemical and physical form specifications of the special nuclear materials.

The requested contents of the GE-2000 package include solid form special nuclear materials. However, the SAR provides no specifications for the chemical (e.g., compound, pure metal, etc.) and the physical (e.g., solid metal, particulate, etc.) forms of these special nuclear materials. Although SAR page 5-4 states "*[t]here are no significant gamma or neutron sources in the SNM contents, thus this content type is not applicable for the shielding analysis, as it is not limited by dose rate or thermal calculations*," this statement does not identify if these special nuclear materials have ever been irradiated or if they are products of reprocessed irradiated materials. The applicant needs to provide specific descriptions of the chemical and physical forms for these special nuclear materials.

This information is needed to verify compliance with 10 CFR 71.33(b)(1), 10 CFR 71.33(b)(3), and 10 CFR 71.55(e)(1).

GEH Response

At this time, GEH is no longer pursuing special nuclear material as a content. Revision 1 of NEDE-33866P will remove such content; therefore, RAI 6.1 regarding the chemical and physical form specification of special nuclear material is no longer applicable.

6.2 Provide specifications for all rod types to be shipped by the GE-2000 package and demonstrate that the criticality safety analyses presented in the SAR bound all fuel types to be shipped.

The applicant performed criticality safety analyses for the GE-2000 package containing irradiated fuel rod segments. On page 5-4 of the SAR, the applicant states that it used the GE 10x10 as the design basis fuel assembly. However, the applicant indicates on SAR page 6-5 that the fuel rod outside radius can vary from 0.2 to 0.5 cm to encompass a variety of fuel designs. Therefore, staff is unable to determine if the GE 10x10 fuel rods are bounding. The applicant needs to provide specifications for all rod types to be shipped by the GE-2000 package and demonstrate that the criticality safety analyses, which use GE 10x10 BWR fuel rod design as the design basis fuel assembly, bound all fuel types to be shipped.

This information is needed to verify compliance with 10 CFR 71.33(b)(3) and 10 CFR 71.55.

GEH Response

At this time, GEH is no longer pursuing irradiated fuel as a content. Revision 1 of NEDE-33866P will remove such content; therefore, RAI 6.2 regarding justification that the criticality safety analysis bounds all irradiated fuel types to be shipped is no longer applicable.

Operations Review

7.1 Clarify how segmented fuel rods with decay heat less than 1500 watts are shored, and revise the Operating Procedures in Chapter 7 if necessary.

On SAR page 1-4, when discussing the allowable contents and corresponding packaging requirements, the Safety Analysis Report for the GE-2000 package states: "*This may include irradiated fuel rods, irradiated hardware and byproducts, Co-60 isotope rods, or special nuclear material (SNM). The following are requirements for all shipments:*

a) The maximum quantity of material per package shall not exceed 5,450 lb, including all cask internals and contents.

b) All contents shipped shall be in solid form.

c) All configurations require the use of the HPI.

d) All contents shall be shipped in Configuration 1 or Configuration 2 depending on decay heat. The decay heat limits for shipping Configuration 1 and Configuration 2 are outlined in Table 1.2-1. ***See content specifics below as to whether a content configuration requires the use of the HPI material basket****.*"

In addition, on page 6-2 of the SAR, the applicant states: "*For all contents, shoring components such as rod holders or the HPI material basket* ***may be*** *present.*" Also, on page 7-4 of the SAR, the applicant states: *"The use of the HPI material basket is not required for Configuration 1, but may be used as a shoring component*." However, Figure 1.2-5 of the SAR seems to imply that both the rod [[ ]] holder and the material basket are required to hold the segmented fuel rods.

The applicant should clearly identify if the rod [[ ]] holder is required for transporting segmented fuel rods and the conditions for which the rod segment holder is required. The applicant should also revise the Chapter 7 Operating Procedures, if necessary, to provide clear instructions for loading segmented fuel rods.

This information is needed to verify compliance with 10 CFR 71.87(f).

GEH Response

GEH is no longer pursuing the transport of irradiated fuel rods or special nuclear material. Revision 1 of NEDE-33866P will be revised to clarify that the GE-2000 package is only to be used for transport of irradiated hardware and byproducts or Co-60 isotope rods.

The material basket is required for transport of Co-60 isotope rods under all conditions. It is not required for transport of irradiated hardware and byproducts. Revision 1 of NEDE-33866P will be revised to clarify that the material basket is required for transport of Co-60 isotope rods, but not for irradiated hardware and byproducts.

The rod segment holders are optional and may be used to aid in the loading and shoring of Co-60 rods in the material basket. Rod segment holders are not required for shielding, impact, or geometry concerns. Revision 1 of NEDE-33866P will be revised to clarify that rod segment holders may be used for loading and shoring of Co-60 rods in the material basket but are not credited for safety.

7.2 Identify appropriate torque ranges for the Section 7 torque values.

The Section 7 torque values are exact numbers which implies the package cannot be safely transported if torque values above and below these values are employed. Package user personnel will also have difficulty applying such exact torque values. Therefore, the applicant should specify a range of torque values to clarify what is the acceptable package configuration and to facilitate package assembly.

This information is needed to ensure compliance with 10 CFR 71.33(a)(5) and 10 CFR 71.87(f).

GEH Response

Lifting Ear Bolt Torque

Per Reference 7.2-1, Section 6.1.4.b, Page 6-2, the current lifting ear bolt torque requirement is 600 ft-lbs lubricated. No torque tolerance is specified. To ensure proper preload and an adequate bolt fatigue life, the torque tolerance is set to ±20 ft-lbs. The 600 ft-lb value is set as nominal. Therefore, the torque specification for the lifting ears becomes 600±20 ft-lb. The following lifting ear bolt stress and fatigue life evaluation determines the effect of the revised lifting ear bolt tolerance specification.

Lifting Ear Bolt Preload Evaluation

J. E. Shigley and L. D. Mitchell (Reference 7.2-2, Page 382) recommend the bolt preload (Fi) be between 60% and 90% of the proof load. The proof load is equal to 85% of the yield strength (S_y) multiplied by the tensile stress area (A_t). For a torque of 600±20 ft-lbs, the corresponding preload, proof load and percent of proof load are determined as follows:

$F_i = T/(kd)$

% proof load = [F_i / proof load] x 100%

where:

T = torque = 600±20 ft-lb = 7,200±240 in-lb

d = bolt thread nominal diameter = 1.0 in (NEDE-33866P, Drawings 101E8718 and 105E9520)

k = torque coefficient = 0.2 (Reference 7.2-2, Page 378)

proof load = proof strength x A_t = 43,762 lbs

proof strength = 0.85 S_y = 72,250 psi

A_t = thread tensile area = 0.6057 in^2 (NEDE-33866P, Page 2-164)

S_y = Yield Strength at Room Temperature = 85,000 psi (NEDE-33866P, Table 2.2-8)

Table 7.2-1 summarizes the bolt preload, bolt proof load and % proof load for all three lifting ear bolt torque values. As indicated, maximum, nominal, and minimum torques produce loads within the recommended range of 60% to 90% of proof load.

Table 7.2-1: Lifting Ear Bolt Percent Proof Load

Lifting Ear Bolt Torque	**Torque Value (ft-lbs)**	**Bolt Preload (lb)**	**Proof Load (lb)**	**Percent Proof Load**
Maximum	620	37,200	43,762	85%
Nominal	600	36,000		82%
Minimum	580	34,800		80%

Stresses Produced by Maximum Bolt Preload:

Bolt thread tension

$\sigma = F_{i\,Max}/A_i$ (NEDE-33866P, Page 2-165)

$= 37{,}200/0.6057 = 61{,}417$ psi

Bolt thread stripping

$\tau_s = F_{i\,Max}/A_s$ (NEDE-33866P, Page 2-165)

$= 37{,}200/3.164 = 11{,}757$ psi

Tapped thread stripping

$\tau_t = F_{i\,Max}/A_n$ (NEDE-33866P, Page 2-165)

$= 37{,}200/4.054 = 9{,}176$ psi

Minimum bearing stress between cask and ear

$\sigma_{ib} = (\#\text{ of bolts})\, F_{i\,Min}/\text{Contact Area}$ (NEDE-33866P, Page 2-165)

$= 4(34{,}800)/6.0(10.0) = 2{,}320$ psi

The initial bearing pressure, σ_{ib}, is assumed to be uniform over the contact area. The minimum bearing pressure should not be exceeded by the tensile stress, σ_{tb}.

$\sigma_{tb} = 6M/(bd^2) = 2{,}120 \text{ psi} < 2{,}320 \text{ psi} = \sigma_{ib}$ (NEDE-33866P, Page 2-166)

where:

M = the moment produced by Load Case I or III on a standard ear bolt

= 212.4 k-in (NEDE-33866P, Page 2-163)

b = base of contact area = 6.0 in (NEDE-33866P, Drawing 105E9520, Sheet 1, Coordinate D3)

d = height of the contact area = 10.0 in (NEDE-33866P, Drawing 105E9520, Sheet 1, Coordinate E8)

The stress state at the standard lifting ear mounting plate interface for minimum preload is illustrated in Figure 7.2-1.

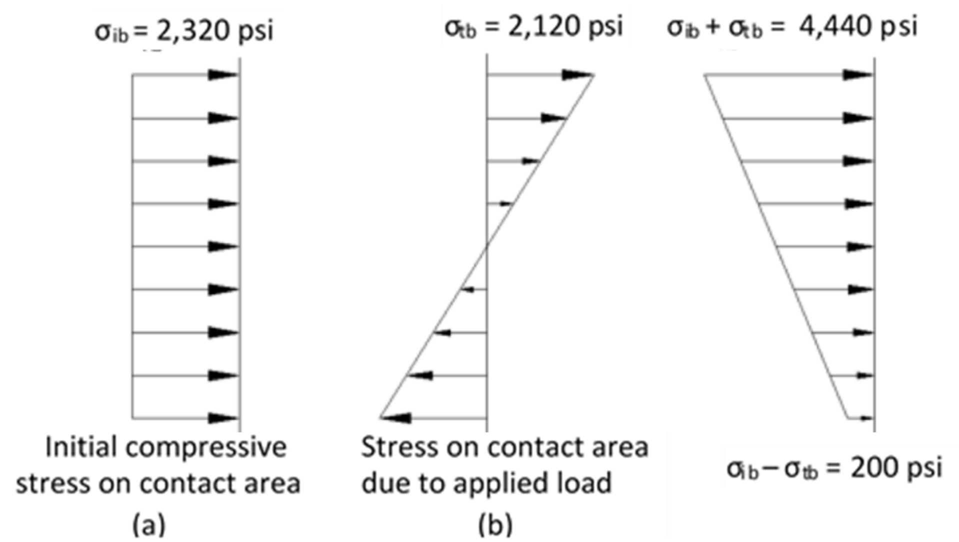

Figure 7.2-1: Stress State at the Standard Lifting Ear / Mounting Plate Interface

Bolt Fatigue Analysis

Bolt and Load Data: (NEDE-33866P, Page 2-167)

Thread Form:	1-8UNC-2A
Bolt Material:	ASTM A193-B6
Minimum Yield Strength:	85,000 psi
Operating Temperature:	250°F
Modulus of Elasticity:	$28.1(10)^6$ psi
Maximum Tensile Stress:	61,417 psi (calculated above for the maximum preload)
Maximum Shear Stress:	14,600 psi*

* Maximum shear neglects the shear reducing effect of friction between the ear and cask body.

The maximum cyclic stress is due to a combination of preload stress and lifting shear stress. The maximum principle stress is:

$$\sigma_{Max} = \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau^2} = \frac{61{,}417}{2} + \sqrt{\left(\frac{61{,}417}{2}\right)^2 + 14{,}600^2} = 64{,}711 \text{ psi}$$

From ASME Section III (Reference 7.2-3) NB 3232.3, the fatigue strength reduction factor to be used is 4.0. Because the fatigue curve (Reference 7.2-3, Figure I-9.1, Page 12) is based on a modulus of elasticity of $30(10)^6$ psi and the bolt has a modulus of elasticity of $28.1(10)^6$ psi, the stress range is given by:

$$S_r = 64{,}711(4.0)[30(10)^6/28.1(10)^6] = 276.3 \text{ ksi}$$

The alternating component is one-half of the range:

$$S_a = S_r/2 = 276.3/2 = 138.2 \text{ ksi}$$

The number of cycles to fatigue failure is determined from Reference 7.2-3, Table I-9.0, Figure I-9.4: MNS $\leq 2.7S_m$. The number of cycles to failure is calculated using the procedure defined in Reference 7.2-3, Table I-9.0 general note (b):

$$\text{Fatigue Limit} = 500\ (1{,}000/500)^{\text{Log}(143/138.2)/\text{Log}(143/100)} = 500\ (2)^{0.0955} \text{ cycles}$$

$$\text{Fatigue Limit} \approx 530 \text{ cycles}$$

Assuming an average of 4 cycles/usage and 12 usages per year, the expected life of the bolts is:

$$\text{Bolt life} = 530/[4(12)] \approx 11 \text{ years}$$

The results of the previous lifting ear bolt load and stress evaluation support the lifting ear bolted joint design for the Model 2000 transport container plus high performance insert (HPI) with a decay heat of 1500 W and the revised bolt torque of 600±20 ft-lb.

<u>Overpack Bolt Torque</u>

Per Reference 7.2-1, Section 6.4.h, Page 6-10, the current overpack bolt torque requirement is 100 ft-lbs dry. No torque tolerance is specified. A reasonable torque tolerance of ±5%, ±5 ft-lbs, is added to the specification. Maintaining the 100 ft-lb value as nominal, the revised torque requirement for the overpack bolts is 100±5 ft-lb. NEDE-33866P, Revision 0, does not contain an evaluation for the loading on these bolts. The following overpack bolt stress and fatigue life evaluation follows the methodology of Reference 7.2-4, Section 2.7.1.5. It includes the effect of the bolt torque requirement change and the loading associated with the Model 2000 transport container with the HPI. The heat decay loading is 1500 W.

<u>Overpack Bolt Stresses and Fatigue Life</u>

This analysis is based on the procedure developed in Reference 7.2-4, Subsection 2.10.7, which was developed to account for the overpack fastener failure during the quarter-scale model side drop test. Once the procedure was satisfactorily developed to explain the fastener failure, it was used to redesign the fastening system. This section presents the steps and results of this analysis as applied to the Model 2000 with the HPI.

The Model 2000 transport package overpack is fastened together with 15 equally spaced ASTM A-540 Grade B22, Class 3 or equivalent 7/8-9 UNC socket head shoulder bolts. The adequacy of these fasteners is determined by comparing the service loads (from the hypothetical accident conditions (HAC)) to the allowable loads, using the criteria given in the ASME Code, Section III, Division 1, Appendix F.

Fatigue for the overpack bolts is evaluated by comparing the endurance stress limit to the corresponding preload and normal operating stress. With this information and the estimated frequency of cask use, the life expectancy of the bolts is determined.

Bolts: 7/8-9 UNC-2A, ASTM A540 Grade B22, Class 3, 15 equally spaced

(NEDE-33866P, Drawings 101E8719 and 105E9521)

Tensile area of threaded portion = 0.462 in^2 (Reference 7.2-4, Section 2.7.1.5)

Temperature = 192°F (NEDE-33866P, Figure 3.5.1-2(b), Average of 175.0°F and 209.8°F)

Proof Strength = Minimum Yield Strength x 85% = 130,000 (0.85) = 110,500 psi

(Reference 7.2-4, Section 2.7.1.5)

Loading: The highest stresses for the overpack fasteners occur during the HAC side drop accident condition. The maximum load is calculated for an impact acceleration of 161.9 g's (NEDE-33866P, Table 2.7.1-1).

Bolt Stresses – HAC Conditions

For the side drop case, the load is applied to the overpack junction as shown in Figure 7.2-2. The overpack is modeled as a simple beam with the force of the cask and contents as a distributed load and the neutral axis at the side of the overpack opposite the side of impact.

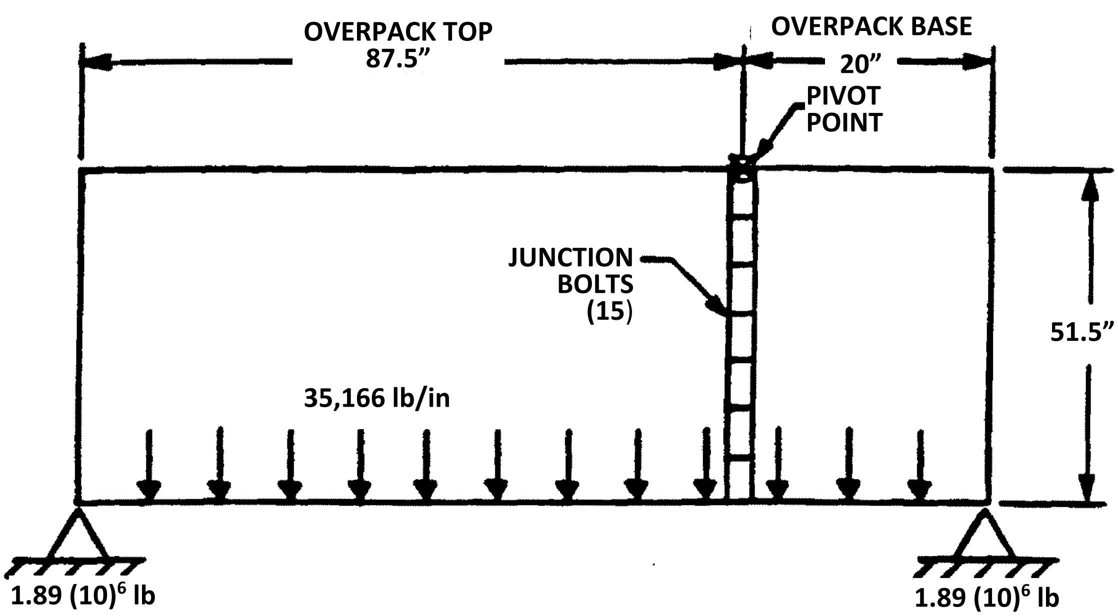

Figure 7.2-2: Overpack Loading, HAC Side Drop

The distributed load equals the weight of the cask (cask body and closure lid) and contents (HPI assembly + material basket + content and shoring) times the acceleration, divided by the length between toroidal reaction points:

Distributed Load = WG/L = 35,166 lb/in

where:

W = (16,000 + 1,900) + (5,133 + 114 + 203) = 23,350 lb

(NEDE-33866P, Table 2.1-3)

G = 161.9 g HAC Side Drop Cold

(NEDE-33866P, Table 2.7.1-1)

L = Overpack vertical length – toroid diameter

L = 131.50 – 24 = 107.5 in

(NEDE-33866P, Overpack Drawings 101E8719 and 105E9521)

The total load to be reacted is:

$F_T = WG = 3.780(10)^6$ lb

The force at each reaction point is:

$F_R = 0.5F_T = 1.890(10)^6$ lb

Figure 7.2-3 shows a free body diagram of the overpack top. The distributed load from the cask is applied as a point load so that the moments can be calculated and the bolt loads determined.

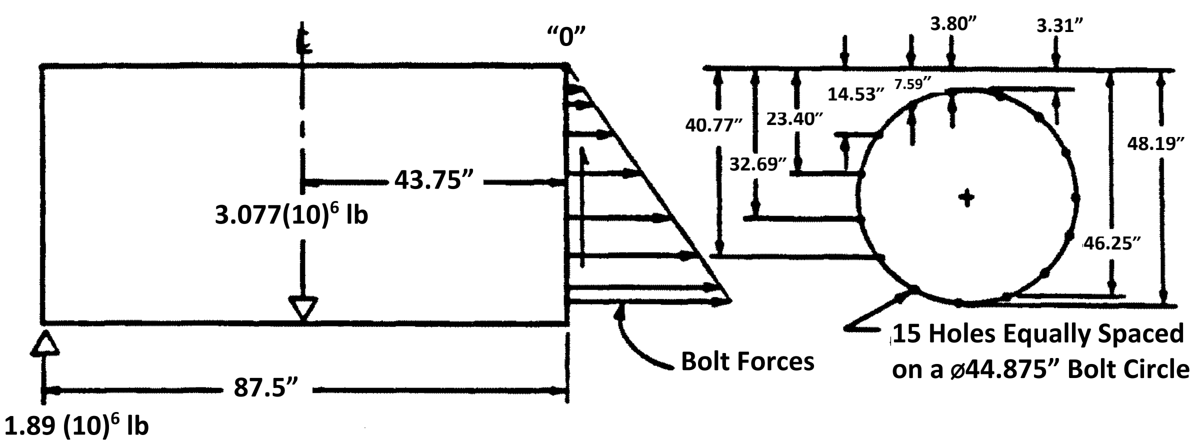

Figure 7.2-3: Free Body Diagram of Overpack Top

Summing the moments about the pivot point "0" yields the following equation:

$$\Sigma M_0 = 0 = -1.89(10)^6 (87.5) + 3.077(10)^6 (43.75) + k (48.19)^2 +$$
$$2k (46.25)^2 + 2k (40.77)^2 + 2k (32.69)^2 + 2k (23.40)^2 +$$
$$2k (14.53)^2 + 2k (7.59)^2 + 2k (3.80)^2$$

Solving for k yields:

$$k = 3.0756(10)^7/ [48.19^2 + 2(46.25^2 + 40.77^2 + 32.69^2 + 23.40^2 + 14.53^2 + 7.59^2 + 3.80^2)]$$

$$k = 2{,}241 \text{ lb/in}$$

The maximum force on a bolt occurs at the point farthest from the pivot point, so the maximum bolt load is:

$$F_{S\ Max} = (2{,}241)\ 48.19 = 107{,}994 \text{ lb}$$

Because the bolts are loaded in double shear on the shoulder (see Figure 7.2-4), the maximum shear stress in the bolt material is:

$$\tau_{Max} = F_{S\ Max} /(2A_S) = 36{,}362 \text{ psi}$$

where:

A_S = Area of bolt shoulder = $0.25\pi D_S^2$ = 1.485 in^2

D_S = Diameter of bolt shoulder = 1.375 in

The allowable shear stress in the bolt for HAC conditions is $0.42S_U$ (NEDE-33866P, Table 2.1-2).

where:

S_U = Ultimate strength for the bolts = 145,000 psi (NEDE-33866P, Table 2.2-9)

$$\tau_{All} = 0.42S_U = 60{,}900 \text{ psi} > \tau_{Max} = 36{,}362 \text{ psi}$$

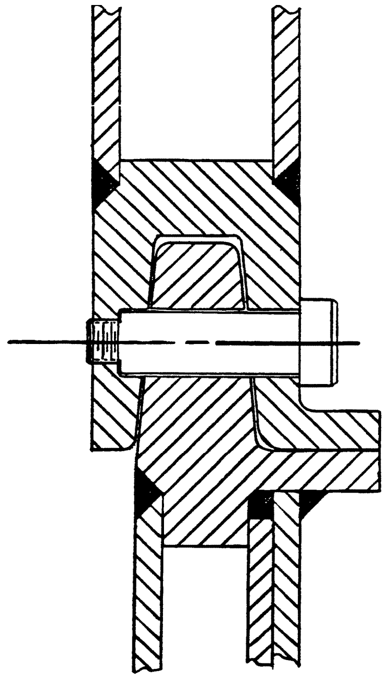

Figure 7.2-4: Overpack Junction

Bolt Stresses – Normal Conditions of Transport (NCT) Conditions

During normal use, the overpack shoulder bolt is subjected to two stresses. One is the stress due to preload and acts on the reduced cross sectional area between the threaded region and the shoulder. The other stress is due to the shear from lifting the package by the top part of the overpack. Fatigue life for each stress case is evaluated to determine the limiting value.

Preload Stress:

Because the bolt is loaded in shear, preloading is only required to prevent its loosening during transport. To further ensure that the bolt will not come loose during transport, an adhesive/sealant compound is applied to the bolt threads prior to installation. The required torque for the overpack bolts is changed to provide a tolerance of ±5% with a nominal torque of 100 ft-lb. Therefore, the new torque value is 100±5 ft-lb.

The maximum preload on the bolt is:

$P = 5T_{Max} / D_{Nom} = 7{,}200$ lb

where:

$T_{Max} = 100 + 5 = 105$ ft-lb = 1,260 in-lb

D_{Nom} = Nominal thread size = 7/8 in = 0.875 in

The area of the reduced cross section between the threads and the shoulder is:

$A = 0.25\ \pi\ (0.726)^2 = 0.414\ in^2$ (Reference 7.2-4, Section 2.7.1.5, Page 2-139)

The tensile stress in this region is:

$\sigma_T = P/A = 7{,}200/0.414 = 17{,}391$ psi << Proof Strength = 110,500 psi

From ASME NB 3232.3 (Reference 7.2-3), the fatigue strength reduction factor is 4.0. The modulus of elasticity at 192°F is $29.04(10)^6$ psi (Reference 7.2-7, Table TM-1, Material Group C, Page 785). Because the fatigue curve (ASME Section III, Figure I-9.4, Page 12) is based on a modulus of elasticity of $30(10^6)$ psi, the stress range is given by:

$S_r = 17{,}391\ (4.0)\ [\ 30(10)^6/29.04(10)^6] = 71{,}864$ psi

The alternating component is one-half of the range:

$S_a = S_r/2 = 71{,}864/2 = 35{,}932$ psi

The number of cycles to fatigue failure is determined from Reference 7.2-3, Table I-9.0, Figure I-9.4: MNS ≤ $2.7S_m$. The number of cycles to failure is calculated using the procedure defined in Table I-9.0, general note (b):

Fatigue Limit = $5{,}000\ (10{,}000/5{,}000)^{\text{Log}(45/35.9)/\text{Log}(45/34)} = 5{,}000\ (2)^{0.806}$ cycles

Fatigue Limit ≈ 8,700 cycles

Assuming an average of 2 cycles/usage and 12 usages per year, the expected life of the bolts is:

Bolt life = 8,700/[2(12)] = 362 years

<u>Lifting Shear Stress</u>:

The weight transferred through the bolts during lifting of the assembled package is equal to the combined weight of the cask, HPI, contents, and overpack base. This total combined lifting weight is:

$W_T = (W_{\text{cask body}} + W_{\text{cask lid}}) + W_{\text{HPI}} + (W_{\text{material basket}} + W_{\text{contents + shoring}}) + W_{\text{overpack base}}$

$= (16{,}000 + 1{,}900) + 5{,}133 + (114 + 203) + 3{,}633 = 26{,}983$ lb

(NEDE-33866P, Table 2.1-3. For overpack base see Table 7.2-2 below)

The weight of the overpack base is determined from Reference 7.2-5, Table 6.2-1, as summarized in Table 7.2-2.

Table 7.2-2: Overpack Base Weight

Assembly ID	Component Description	Weight (lb)
2	End Plate	74.05
4	Stiffening Ring	147.12
5	Gusset Plate	89.20
6	Gusset	88.77

Assembly ID	Component Description	Weight (lb)
7	Tie Down Gusset	37.74
8	Stiffening Ring	143.52
12	Base Outer Shell	155.22
13	Base Inner Shell	110.18
14	Bottom Plate Inside	246.24
15	Spacer Tube	91.44
16	Toroid	1,614.27
19	Base Bolting Ring	594.01
25	Cask Positioning Block	14.09
26	Cask Support Plate	200.89
27	Energy Absorbing Honeycomb	26.41
	Total Overpack Base Weight =	3,633.15

The area of the 15 bolts loaded in double shear is:

A_T = Total area of bolt shoulders = $(2)(15)(0.25)\pi(1.375)^2 = 44.55\ in^2$

The bolt shearing stress associated with a vertical lift of the package and contents is:

$\tau_{Lifting} = W_T / A_T = 26{,}983/44.55 = 606$ psi

Correcting for fatigue strength and modulus of elasticity gives a stress range of:

$\tau_r = 606\ (4.0)\ [30(10)^6/29.04(10)^6] = 2{,}504$ psi

The alternating component is:

$\tau_a = \tau_r/2 = 2{,}504/2 = 1{,}252$ psi

The fatigue limit is > 10^6 cycles.

The results of the revised overpack bolt load and stress evaluation support the overpack bolted joint design for the Model 2000 transport container plus HPI with a decay heat of 1500 W and the revised overpack bolt torque of 100±5 ft-lb.

Cask Closure Lid Bolt Torque

Per Reference 7.2-1, Section 6.3.4.d, Page 6-8, the closure lid bolt torque requirement is 690 ft-lbs lubricated. No torque tolerance is specified. The 690 ft-lb torque is specified for the low temperature aluminum retainer seal, Configuration 1, and was required to qualify the low temperature seal design. To ensure the seal functions properly during service, the minimum bolt torque is set to 690 ft-lb while the tolerance is set to ±30 ft-lb. Therefore, the revised closure lid bolt torque is 720±30 ft-lbs. Per NEDE-33866P, the current lid closure bolt load and stress evaluation was performed for the Configuration 2 stainless steel seal retainer and 500 ft-lb of bolt torque. Following the procedure presented in NEDE-33866P, the lid closure bolt load and stress analysis is revised for the Configuration 1 seal (aluminum retainer) and 720±30 ft-lb bolt torque. The load and stress relations and criteria can be found in NEDE-33866P and NUREG/CR-6007 (Reference 7.2-6). The following tables summarize the revised evaluation. Changes relative to NEDE-33866P Revision 0 are shown in ***bold italic***. The closure lid bolt torque is conservatively evaluated at Configuration 2 temperatures.

Table 2.12.4-7. Model 2000 Stress Analysis Design Input Parameter

(***Revisions*** to NEDE-33866P Revision 0)

Parameter	Variable	Input	Units
Number of Bolts	N_b	15	---
Lid Diameter at Bolt Circle	D_{lb}	32.25	in
Lid Diameter at Gasket	D_{lg}	29.25	in
Nominal Bolt Diameter	D_b	1.25	in
Lid Diameter at Inner Edge	D_{li}	28	in
Lid Diameter at Outer Edge	D_{lo}	34.75	in
Equivalent Thickness of Lid	t_l	***7.89***	in
Thickness of Lid Flange	t_{lf}	1.5	in
Thickness of Cask Wall	t_c	6	in
Bolt Length Between the Top and Bottom of Closure Lid at Bolt Circle	***l_b***	***1.5***	***in***
Bolt Engagement Length	BEL	1.625	in
Young's Modulus for Lid	E_l	2.59E+07	psi
Young's Modulus for Cask	E_c	2.59E+07	psi
Young's Modulus for Bolt	E_b	2.74E+07	psi
Poisson's Ratio for Lid	N_{ul}	0.31	---
Poisson's Ration for Cask	N_{uc}	0.31	---
Lid Thermal Expansion Coefficient	a_l	9.70E-06	1/°F
Bolt Thermal Expansion Coefficient	a_b	7.30E-06	1/°F
Maximum Weight of Cask Contents	W_c	5,450	lb
Weight of Cask Lid	W_l	1,900	lb

Parameter	Variable	Input	Units
Dynamic Load Factor	DLF	1	---
Preload Torque	***QNOM***	***720***	***lb-ft***
Preload Torque Tolerance	***QTOL***	***30***	***lb-ft***
Maximum Preload Torque	***QMAX***	***9,000***	***lb-in***
Minimum Preload Torque	***QMIN***	***8,280***	***lb-in***
Nut Factor for Preload Torque	K_q	0.15	---
Gasket Seating Width	G_b	0.109	in
Gasket Seating Stress	G_y	***8,800***	psi
Gasket Factor	G_M	***4***	---
Wall Thermal Expansion Coefficient	a_c	9.70E-06	1/°F
Basic Allowable Stress Limit	S_m	77,133	psi
Minimum Yield Strength	S_y	115,700	psi
Minimum Ultimate Strength	S_u	145,000	psi
Pressure Inside the Closure Lid	P_{li}	30	psi
Pressure Outside the Closure Lid	P_{lo}	15	psi
Pressure Inside the Cask Wall	P_{ci}	30	psi
Pressure Outside the Cask Wall	P_{co}	15	psi
Temperature Change of the Closure Lid	T_l	117.5	°F
Temperature Change of the Closure Bolt	T_b	111.9	°F
Temperature Change of the Cask Wall	T_c	118.0	°F
Temperature Change of Inner Surface of Closure Lid	T_{li}	116.8	°F
Temperature Change for Outer Surface of Closure Lid	T_{lo}	118.1	°F

Parameter	Variable	Input	Units
Maximum Rigid Body Impact Acceleration	A_i	25.0	g
Impact Angle Between the Cask Axis and the Target Surface	X_i	90.0	°
Maximum Axial Vibration Acceleration at the Cask Support	ava	2.0	g
Maximum Transverse Vibration Acceleration at the Cask Support	avt	5.0	g
Vibration Transmissibility of Acceleration between the Cask Support and the Closure Lid	vtr	1.0	g

Table 2.12.4-8. Forces/Moments Results (NCT)

(***Revisions*** to NEDE-33866P Revision 0)

Load Condition	Forces/Moments	Variable	Magnitude	Units
PRESSURE	Non-Prying Tensile Bolt Force	F_a	671.96	lb
	Shear Bolt Force Per Bolt	F_s	***3,113.55***	lb
	Fixed-Edge Closure-Lid Force	F_f	120.94	lb
	Fixed-Edge Closure-Lid Moment	M_f	487.53	lb-in
TEMPERATURE	Non-Prying Tensile Bolt Force	F_a	10,856.79	lb
	Shear Bolt Force Per Bolt	F_s	***-9,701.92***	lb
	Fixed-Edge Closure-Lid Force	F_f	0.00	lb
	Fixed-Edge Closure-Lid Moment	M_f	***2,455.49***	lb-in
VIBRATION	Non-Prying Tensile Bolt Force	F_a	253.33	lb
	Shear Bolt Force Per Bolt	F_s	633.33	lb
	Fixed-Edge Closure-Lid Force	F_f	37.51	lb
	Fixed-Edge Closure-Lid Moment	M_f	151.20	lb-in

Load Condition	Forces/Moments	Variable	Magnitude	Units
PRELOAD	Non-Prying Tensile Bolt Force Per Bolt	F_a	***48,000.00***	lb
	Torsional Bolt Moment Per Bolt	M_t	***4,500.00***	lb-in
GASKET	Axial Load for Gasket Seating	F_a	***5,876.16***	lb
	Axial Load for Gasket Operation	F_a	***80.13***	lb
	Torque Due to Gasket	M_t	***550.89***	lb-in
PRYING	Axial Load Due to Prying	F_a	***-2,339.42***	lb
	Bending Moment Due to Prying	M_{bb}	***9.99***	lb-in

Table 2.12.4-9. Forces/Moments Results (HAC)

(***Revisions*** to NEDE-33866P Revision 0)

Load Condition	Forces/Moments	Variable	Magnitude	Units
PRESSURE	Non-Prying Tensile Bolt Force	F_a	671.96	lb
	Shear Bolt Force Per Bolt	F_s	***3,113.55***	lb
	Fixed-Edge Closure-Lid Force	F_f	120.94	lb
	Fixed-Edge Closure-Lid Moment	M_f	487.53	lb-in
TEMPERATURE	Non-Prying Tensile Bolt Force	F_a	10,856.79	lb
	Shear Bolt Force Per Bolt	F_s	***-9,701.92***	lb
	Fixed-Edge Closure-Lid Force	F_f	0.00	lb
	Fixed-Edge Closure-Lid Moment	M_f	***2,455.49***	lb-in
IMPACT	Non-Prying Tensile Bolt Force	F_a	16,415.00	lb
	Shear Bolt Force Per Bolt	F_s	0.00	lb
	Fixed-Edge Closure-Lid Force	F_f	2,430.26	lb
	Fixed-Edge Closure-Lid Moment	M_f	9,796.98	lb-in

Load Condition	Forces/Moments	Variable	Magnitude	Units
PRELOAD	Non-Prying Tensile Bolt Force Per Bolt	F_a	***48,000.00***	lb
	Torsional Bolt Moment Per Bolt	M_t	***4,500.00***	lb-in
GASKET	Axial Load for Gasket Seating	F_a	***5,876.16***	lb
	Axial Load for Gasket Operation	F_a	***80.13***	lb
	Torque Due to Gasket	M_t	***550.89***	lb-in
PRYING	Axial Load Due to Prying	F_a	***-2,149.02***	lb
	Bending Moment Due to Prying	M_{bb}	***41.13***	lb-in

Table 2.12.4-10. Total Loads/Bolt Stresses (NCT)

(***Revisions*** to NEDE-33866P Revision 0)

Total Loads / Bolt Stresses	Variable	Magnitude	Units
Total Bolt Axial Load	F_a	***63,318.83***	lb
Total Bolt Shear Load	F_s	***-5,955.04***	lb
Total Bolt Bending Moment	M_b	***3,094.22***	lb-in
Total Bolt Torsional Moment	M_t	***4,500.00***	lb-in
Average Bolt Direct Stress	S_{ba}	***65,335.10***	psi
Average Bolt Shear Stress	S_{bs}	***-6,144.66***	psi
Maximum Bending Stress	S_{bb}	***22,994.83***	psi
Maximum Shear Stress	S_{bi}	***16,720.98***	psi
Maximum Stress Intensity	S_{bt}	***90,827.37***	psi

Table 2.12.4-11. Total Loads/Bolt Stresses (HAC)

(***Revisions*** to NEDE-33866P Revision 0)

Total Loads / Bolt Stresses	Variable	Magnitude	Units
Total Bolt Axial Load	F_a	***79,670.89***	lb
Total Bolt Shear Load	F_s	***-6,588.37***	lb
Total Bolt Bending Moment	M_b	***12,781.13***	lb-in
Total Bolt Torsional Moment	M_t	***4,500.00***	lb-in
Average Bolt Direct Stress	S_{ba}	***82,207.82***	psi
Average Bolt Shear Stress	S_{bs}	***-6,798.17***	psi
Maximum Bending Stress	S_{bb}	***94,983.60***	psi
Total Bolt Shear Stress	S_{bt}	***16,720.98***	psi

Table 7.2-3 provides a maximum stress analysis of the closure bolts for NCT based on Reference 7.2-6, Table 6.1.

Table 7.2-3: Maximum Stress Analysis of Closure Bolts – NCT

(***Revisions*** to NEDE-33866P Revision 0)

Stress Limits - NCT Maximum Stress Analysis	NUREG-6007 Table 6.1		
Average Tensile Stress < Allowable Tensile Stress: $S_{ba} < S_m = 2/3\ S_y$	S_m	***77,133.33***	psi
Average Shear Stress < Allowable Shear Stress: $S_{bs} < 0.6 S_m$	$0.6\ S_m$	***46,280.00***	psi
Stress Ratio for Average Tensile Stress	R_t	S_{ba} / S_m	
Stress Ratio for Average Shear Stress	R_s	$S_{bs} / 0.6 S_m$	
Stress Ratio Criteria	$R_t^2 + R_s^2$	< 1	
Allowable Maximum Stress Intensity for S_u > 100 ksi	$1.35\ S_m$	***104,130.00***	psi

Table 7.2-4 provides, with revisions, the NCT maximum stress analysis (Note that this information is not currently in tabular format but is presented in the text of NEDE-33866P, Revision 0, Section 2.12.4.2.16, “Limits on Bolt Stresses Results”).

Table 7.2-4: Maximum Stress Analysis of Closure Bolts – NCT Summary

(***Revisions*** to NEDE-33866P Revision 0)

Stress Evaluation – NCT Maximum Stress Analysis	Magnitude		Allowable	Units
Average Bolt Direct Stress	***65,335.10***	<	77,133.33	psi
Average Shear Stress	***-6,144.66***	<	46,280.00	psi
Stress Ratio for Average Tensile Stress, R_t	***0.8474***	----	----	----
Stress Ratio for Average Shear Stress, R_s	***-0.1328***	----	----	----
Stress Ratio Criteria, $R_t^2 + R_s^2$	***0.7351***	<	1	----
Maximum Stress Intensity	***90,827.37***	<	104,130.00	psi

Table 2.12.4-12. Fatigue Analysis Results (NCT)

(***Revisions*** to NEDE-33866P Revision 0)

Parameter	Variable	Value	Units
Operating Stress	$S_{operating}$	***67,487.62***	psi
Vibration Stress	$S_{vibration}$	***261.40***	psi
Fatigue Strength Reduction Factor	RF	4	---
Cumulative Usage Factor	U	1	---
Design Curve Modulus	E_{dc}	30,000,000	psi
Bolt Modulus Used in Analysis	E_a	***27,400,000***	psi
Operating Stress Range	$S_{r\text{-}Operation}$	***295,566.20***	psi
Vibration Stress Range	$S_{r\text{-}Vibration}$	***1,144.82***	psi
Operating Alternating Stress	$S_{a\text{-}Operation}$	***147,783.10***	psi

Parameter	Variable	Value	Units
Vibration Alternating Stress	$S_{a\text{-Vibration}}$	***572.41***	psi
Fatigue Limit for Operating	$N_{a\text{-Operating}}$	***466***	cycles
Fatigue Limit for Vibration	$N_{a\text{-Vibration}}$	1.00E+11	cycles
Number of Operation (Transport) Cycles	$N_{Operation}$	190	cycles
Number of Vibration Cycles	$N_{Vibration}$	1.00E+07	cycles
Accumulated Fatigue Usage	R	***0.4078***	< 1

Table 7.2-5 provides a maximum stress analysis of the closure bolts for HAC based on Reference 7.2-6, Table 6.3.

Table 7.2-5: Maximum Stress Analysis of Closure Bolts – HAC

(***Revisions*** to NEDE-33866P Revision 0)

Stress Limits - HAC Maximum Stress Analysis	NUREG-6007 Table 6.3		
Allowable Tensile Stress – S_{ba} < the smaller of $0.7S_u$ or S_y at temperature	$0.7S_u$	101,500	psi
	S_y	115,700	psi
Allowable Shear Stress - S_{bs} < the smaller of $0.42S_u$ or $0.6S_y$ at temperature	$0.42S_u$	60,900	psi
	$0.6S_y$	69,420	psi
Stress Ratio for Average Tensile Stress - S_{ba} / the smaller of $0.7S_u$ or S_y	R_t	$S_{ba} / 0.7S_u$	---
Stress Ratio for Average Shear Stress - S_{bs} / the smaller of $0.42S_u$ or $0.6S_y$	R_s	$S_{bs} / 0.42S_y$	---
Stress Ratio Criteria	$R_t^2 + R_s^2$	< 1	

Table 7.2-6 provides the HAC maximum stress analysis (Note that this information is not currently in tabular format but is presented in the text of NEDE-33866P, Revision 0, Section 2.12.4.2.16, “Limits on Bolt Stresses Results”).

Table 7.2-6: Maximum Stress Analysis of Closure Bolts – HAC Summary

(***Revisions*** to NEDE-33866P Revision 0)

Stress Evaluation – HAC Maximum Stress Analysis	Magnitude		Allowable	Units
Average Bolt Direct Stress	***82,207.87***	<	101,500	psi
Average Shear Stress	***-6,798.17***	<	60,900	psi
Stress Ratio for Average Tensile Stress, R_t	***0.8099***	----	----	----
Stress Ratio for Average Shear Stress, R_s	***-0.1116***	----	----	----
Stress Ratio Criteria, $R_t^2 + R_s^2$	***0.6684***	<	1	----

The results of the revised cask bolt load and stress evaluation support the cask closure lid bolted joint design for the Model 2000 transport container plus HPI, decay heat of 1500 W, aluminum retainer seal and the revised cask bolt torque of 720±30 ft-lb.

Sections 2 and 7 of NEDE-33866P will be updated based on the re-evaluated bolt loading and stresses and revised bolt torques, respectively.

Cask Body Stresses

The cask body stresses were evaluated for a cask lid bolt preload of 32,000 lb corresponding to a bolt torque of 500 ft-lb (NEDE-33866P, Section 4.1.2) using ANSYS finite element modeling software. The heat decay load was 3000 W for all cases. The cask seal retainer was stainless steel. The cask end drop accelerations for NCT and HAC were 15.5g and 157.5g respectively (NEDE-33866P, Table 2.12.1-1). The cask body ANSYS analysis will be rerun for 3000 W heat decay (conservative), 48,000 cask lid bolt preload (750 ft-lb max torque), stainless seal retainer (conservative), and NCT and HAC accelerations of 15.5g and 157.5g, respectively.

NEDE-33866P, Section 2.7.1.1, "Cask Body Stress Analysis," will be updated upon completion of the ANSYS analysis as described above.

References

7.2-1 GE Specification 22A9380, "Operations and Maintenance of Model 2000 Transport Package," Revision 8.

7.2-2 J. E. Shigley and L. D. Mitchell, Mechanical Engineering Design, 4th edition, New York, United States: McGraw-Hill, 1965.

7.2-3 ASME Boiler and Pressure Vessel Code, Section III, Division 1 – Appendices, "Rules for Construction of Nuclear Facility Components," 2010.

7.2-4 GE Hitachi Nuclear Energy, “Model 2000 Radioactive Material Transport Package Safety Analysis Report,” NEDO-31581, Revision 1, October 2000.

7.2-5 DAHER-TLI Report, CN-14001-102, “Weights and Center of Gravity for the Model 2000 Transport Package,” Revision 1.

7.2-6 NUREG/CR-6007, “Stress Analysis of Closure Bolts for Shipping Casks,” 1992.

7.2-7 ASME BPVC, Section II Materials, Part D Properties (Customary), 2013.

7.3 Revise SAR Section 7.5.2 procedure to include all nuclides that contribute decay heat.

The second step of SAR Section 7.5.2 has several bullets clarifying what nuclides need to be listed in the loading table. The staff did not find an appropriate place for alpha and beta emitting nuclides. Although these nuclides are not significant to external dose rate, they could significantly contribute to decay heat. The applicant should revise this step to ensure users do not inadvertently exclude these nuclides.

This information is needed to verify compliance with 10 CFR 71.33(b)(7), 10 CFR 71.43(g) and 10 CFR 71.87(k).

GEH Response

Step 2 in Section 7.5.2 of NEDE-33866P indicates that those radionuclides included in Table 5.5-30 should be included in the loading table. While Step 2 does provide more guidance for gamma emitting radionuclides, it does not state that alpha and beta radionuclides should be excluded from the loading table.

NEDE-33866P Revision 1 will strengthen the wording of Section 7.5.2 Step 2 to circumvent the human performance error trap of excluding alpha and beta emitters from the loading table.

7.4 Clarify SAR Section 7.5.3 language with respect to the Co-60 content.

SAR Section 7.5.3 contains the procedure for verifying package compliance when shipping Co-60 rods. As stated in RAI 5.4, staff interprets the Co-60 limit to be 17,000 Ci per inch based upon the shielding evaluations provided by the applicant. Since the last three bullets of step 1 do not seem to reflect this limit, staff is unclear what these bullets communicate. The applicant should revise the steps within this procedure as necessary to be consistent with the limit identified in response to RAI 5.4.

This information is needed to verify compliance with 10 CFR 71.47(b) and 10 CFR 71.51(a)(2).

GEH Response

The Co-60 activity limit as indicated in Section 7.5.3 of NEDE-33866P is incorrect. The limit should be based on Ci per inch. Section 7.5.3 will be corrected to coincide with the Ci per inch limit as used in the supporting Chapter 5 shielding analysis.

7.5 Clarify how free form special nuclear material is loaded into the HPI, provide specific descriptions of the required shoring devices for the special nuclear material content, and revise the Chapter 7 Operating Procedures if necessary.

On page 6-2, the applicant states: "*For all contents, shoring components such as rod holders or the HPI material basket may be present.*" On page 7-4, the applicant further instructs the users: "*The use of the HPI material basket is not required for Configuration 1, but may be used as a shoring component.*" Since these statements indicate the material basket is optional, it is unclear how the free form special nuclear material is loaded and restrained in the HPI given the fact that the allowable quantity of special nuclear material (430 grams of U-235) will occupy only about 23 cm^3 of the HPI cavity. The applicant needs to clarify how the free form special nuclear material is loaded into the HPI, provide specific descriptions of the shoring devices required for the special nuclear materials content, and revise the Operating Procedures in Chapter 7 if necessary.

This information is needed to verify compliance with 10 CFR 71.55 and 10 CFR 71.87(f).

GEH Response

GEH is no longer pursuing the transport of irradiated fuel rods or special nuclear material. Revision 1 of NEDE-33866P will be revised to clarify that the GE-2000 package is only to be used for transport of irradiated hardware and byproducts or Co-60 isotope rods.

7.6 Provide specific instructions for what shoring devices are required, when shoring devices are required, and how shoring devices are installed.

SAR Section 7.1 states: "For Configuration 1: Load the contents directly into the HPI with additional shoring as required. For Configuration 2: Load the contents and any additional required shoring (e.g., rod holders) into the HPI material basket and load the material basket into the HPI." These instructions neither specify when shoring is required, what shoring devices are required, nor how to install shoring. The applicant needs to provide more specific instructions for when and what shoring devices are required and how to install them to avoid misloading the package.

This information is needed to verify compliance with 10 CFR 71.87(f).

GEH Response

At this time, GEH is no longer pursuing the Configuration 2 option (3000 W decay heat) for cobalt (Co) isotope transport. Revision 1 of NEDE-33866P will remove such content, and therefore RAI 7.6 regarding Configuration 2 shoring requirements is no longer applicable.

At this time, GEH intends to use the GE-2000 transport container exclusively for Co isotope and irradiated hardware transport. Revision 1 of NEDE-33866P will remove document content pertaining to all transport content except Co-60 isotopes and irradiated hardware.

For the 1500 W decay heat Co isotope contents, a material basket and rod holders (shoring) are required.

Section 7.1 of NEDE-33866P is intended to provide a general sequence of events for initial preparation, loading, and transport of the GE-2000 package including the high performance insert (HPI), shoring and contents. Reference 7.6-1, Section 7.1.2, provides a detailed description for the loading and transport of specific contents into the HPI and cask.

In Section 7.1 of NEDE-33866P, the second sentence of the first paragraph, will be updated as follows:

"Fully trained personnel using approved operating procedures shall carry out all loading operations at the facility. The general sequence for Co-60 isotope transport is as follows:"

In Section 7.1 of NEDE-33866P, the Configuration 1 and Configuration 2 bullets will be replaced by the following bullet:

- "Load the Co isotope rods and the required shoring (e.g., rod holders) into the HPI material basket and load the material basket into the HPI."

Based on the GEH responses to RAIs 7.2 and 7.6, Section 7 of Reference 7.6-1 and Section 7 of NEDE-33866P will be updated to:

- Include the new torque limits for the overpack, lifting ear and cast closure bolts as presented in the response to RAI 7.2,

- Remove all Configuration 2 content,
- Make the material basket and rod holder shoring a requirement for the transport of Co-60 isotope rods, and
- Remove all document content pertaining to all transport content except Co-60 isotopes and irradiated hardware.

Reference

7.6-1 GE Specification 22A9380, "Operations and Maintenance of Model 2000 Transport Package," Revision 8, July 2003.

Acceptance and Maintenance Review

8.1 Clarify the frequency at which periodic leak testing must be performed.

Although the Section 8.2.1.2 periodic inspections are performed either after 12 usages or once within a 12 month period and Section 8.2 identifies leak testing the package to 1×10^{-7} ref cm^3/sec after 12 usages, Section 8.2.2.2 only indicates periodic leak testing must be performed once after the previous 12-month period.

This information is needed to ensure compliance with 10 CFR 71.87(f).

GEH Response

The frequency stated in Section 8.2.1.2 of NEDE-33866P is correct for leak testing. NEDE-33866P Chapter 8 will be updated to clarify the requirements and remove repetitive statements.

8.2 Revise the statement that the fabrication leakage rate testing is required for the “**entire**” containment boundary, not just for the “**primary**” containment boundary.

In Section 4.0, the applicant stated: “The entire primary containment boundary, including containment welds and base metals as shown in Figure 4.1.3-1, are leakage rate tested for fabrication, maintenance, and periodically as defined in Section 8.0.” The applicant needs to revise the statement to clarify that the fabrication leakage rate testing is required on the “entire” containment boundary in accordance with ANSI N14.5, 2014. Use of the phrase “entire primary containment boundary” lacks the requisite precision.

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

GEH Response

In Section 4 of NEDE-33866P, the third sentence will be updated to remove “primary” in the containment boundary description in accordance with ANSI N14.5, 2014.

8.3 Provide the acceptance test results for the Configuration 2 lid seal.

The applicant tested the Configuration 2 cask lid [[ ]] seal, and presents the test results in Reference 8-10 (Report 003N5189 R0, 2016). The applicant should provide the test procedure and test results for staff review to ensure the test procedure is appropriate and the results demonstrate adequate seal performance.

This information is needed to determine compliance with 10 CFR 71.43(f), and 10 CFR 71.51.

GEH Response

At this time, GEH is no longer pursuing the Configuration 2 option (3000 W decay heat). Revision 1 of NEDE-33866P will remove such content; therefore, RAI 8.3 regarding acceptance testing of the Configuration 2 lid seal is no longer applicable.

In Section 7.5.2 of NEDE-33866P Revision 1, the term "criticality" will be corrected to "activity" in the eighth bullet.

In addition to the information requests above, staff identified the following editorial item:

1. The next to last bullet in Section 7.5.2 uses the term “criticality” instead of “activity”.

GEH Response

NEDE-33866P, Section 7.5.2, bullet eight, the term "criticality" will be corrected to "activity".