NRC FORM 618
(8-2000)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE	PAGES
9228	27	71-9228	USA/9228/B(U)-96	1	OF 4

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, "Packaging 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)*

GE-Hitachi Nuclear Energy Americas, LLC
3901 Castle Hayne Road
Wilmington, NC 28401

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

GE Hitachi Nuclear Energy consolidated application dated April 28, 2016, as supplemented.

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.: 2000

(2) Description

The cask body is constructed of two concentric 1-inch thick 304 stainless steel cylindrical shells (ASTM A240) joined at the bottom end to a 6-inch thick 304 stainless steel forging (ASTM A182). The overall packaging dimensions are approximately 131.5 inches in height and 72 inches in diameter, and its gross weight is approximately 33,550 lbs. The cavity of the packaging is approximately 26.5 inches in diameter and 54.0 inches deep.

The cask lid is fully recessed into the cask top flange and secured to the cask body by 15, 1.25-inch diameter socket head screws. The packaging is equipped with a seal test port on the side of the body, a vent port in the lid, and a drain port near the bottom of the packaging. The cask lid utilizes four O-rings in a metal retainer.

The overpack is constructed from two 0.5-inch thick concentric 304 stainless steel cylindrical shells (ASTM A240), separated radially by eight equally spaced tubes and horizontally by two tube sections. A 304 stainless steel toroidal shell impact limiter is attached to each end of the overpack. The overpack opens just above the lower impact limiter for access to the packaging. The top of the overpack is joined to the base by 15, 1-3/8-inch diameter shoulder screws. Gussets on the top and bottom impact limiters provide tie-down points for the package. The lifting devices are detached during transport.

5.(a) (2) Description (Continued)

A high performance insert (HPI) is fabricated from two concentric stainless steel cylindrical shells. The annulus between the cylindrical shells is filled with depleted uranium. The HPI is positioned within the cask cavity by support disks arranged axially to provide uniform support. Vertical lifting arms connect the support disks and also serve as the primary lifting fixtures. The HPI is shielded using encapsulated depleted uranium within both a top and a bottom plug. The top plug has a stepped design and an optional spacer may be added to provide additional shoring.

A material basket is also used for the shipment of contents described in 5(b)(1)(ii).

(3) Drawings

(i) With the exception of packaging Serial No. 2001, the packaging is constructed and assembled in accordance with the following General Electric Company Drawings:

Drawing No.	Drawing Title	Revision
129D4946	Model 2000 Transport Container	12
105E9520	Model 2000 Shipping Cask all S/N's Except S/N 2001	9 (Sheet 1 of 2) 9 (Sheet 2 of 2)
105E9521	Model 2000 Cask Overpack All S/N's Except S/N 2001	7

(ii) Packaging Serial No. 2001 is constructed and assembled in accordance with the following General Electric Company Drawings:

Drawing No.	Drawing Title	Revision
129D4946	Model 2000 Transport Container	12
101E8718	Model 2000 Shipping Cask S/N 2001	17 (Sheet 1 of 2) 17 (Sheet 2 of 2)
101E8719	Model 2000 Shipping Cask Overpack S/N 2001	14

(ii) The HPI and HPI material basket are constructed and assembled in accordance with the following General Electric Company Drawings:

Drawing No.	Drawing Title	Revision
001N8422	GE 2000 HPI and Material Basket Licensing Drawing	3
001N8423	GE 2000 HPI Licensing Drawing	2
001N8424	GE 2000 HPI Material Basket Assembly Licensing Drawing	2
001N8425	GE 2000 HPI Body Licensing Drawing	2
001N8427	GE 2000 HPI Top Plug Assembly Licensing Drawing	2
001N8428	GE 2000 HPI Bottom Plug Assembly Licensing Drawing	2

5.(b) (1) Contents

(i) Irradiated hardware components composed of stainless steels, carbon steels, nickel alloys and zirconium alloys. Irradiated byproducts such as control rods and/or control blades containing either hafnium or boron carbide. The minimum cooling time for either irradiated hardware or irradiated byproducts shall be at least 30 days prior to shipment.

(ii) ^{60}Co as either normal form rods, normal form encapsulated pellets or special form.

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

(i) For the contents described in 5(b)(1)(i), the maximum quantity of material shall not exceed the limits specified in Section 7.5.1 of the safety analysis report.

(ii) For the contents described in 5(b)(1)(ii), the maximum quantity of material shall not exceed the limits specified in Section 7.5.2 of the safety analysis report, and the total activity in any axial 1-inch increment shall be less than or equal to 17,000 Curies.

(iii) For a combination of contents described in 5(b)(1)(i) and 5 (b)(1)(ii), the maximum quantity of material shall not exceed the limits specified in Section 7.5.3 of the safety analysis report.

(iv) The contents described in 5(b)(1)(i) and 5(b)(ii) may contain fissile material provided the quantity of material does not exceed the exempt quantity under 10 CFR 71.15.

(v) The thermal heat load of the package shall not exceed 1500 W.

(vi) The combined weight of the HPI, HPI basket, radioactive material, shoring, and secondary containers shall not exceed 5,450 lbs.

6. The HPI shall be used to transport contents 5(b)(1)(i) and 5(b)(1)(ii).

7. The HPI and the HPI material basket shall be used to transport content 5(b)(1)(ii).

8. Appropriate shoring must be provided as necessary to minimize content movement during accident conditions of transport.

9. The package shall be shipped in a vertical orientation.

10. Air transport is not authorized.

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

(a) The package shall be prepared for shipment and operated in accordance with the Package Operations in Section 7.0 of the application, as supplemented.

(b) The package must meet the Acceptance Tests and Maintenance Program in Section 8.0 of the application, as supplemented.

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

13. Expiration date: March 31, 2023.

REFERENCES

GE Hitachi Nuclear Energy Company application dated April 28, 2016.

Supplements dated: May 4, 2016; June 13, and September 29, 2017; January 9, and February 27, 2018.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

/RA/

John McKirgan, Chief
Spent Fuel Licensing Branch
Division of Spent Fuel Management
Office of Nuclear Material Safety
and Safeguards

Date: April 17, 2018

SAFETY EVALUATION REPORT

Docket No. 71-9228
Model No. 2000
Certificate of Compliance No. 9228
Revision No. 27

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SUMMARY

By letter dated April 28, 2016, as supplemented May 4, 2016, June 13, and September 29, 2017, January 9, and February 27, 2018 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML16119A328, ML16161A016, ML17164A287, ML17272A714, ML18010A082 and ML18058A110 respectively), GE Hitachi Nuclear Energy submitted an application for renewal of Certificate of Compliance (CoC) No. 9228 for the Model No. 2000 package. In addition, the applicant requested a revision to CoC No. 9228 for the Model No. 2000 package and submitted a consolidated safety analysis report (SAR) documenting the results of revised structural, thermal, containment, and shielding evaluations in support of authorizing the use of a new high performance insert (HPI), the use of a new HPI material basket, and the removal of previously authorized contents. In responding to a request for additional information, the applicant revised their application to remove fissile material as authorized content and to preclude transporting contents with a heat load exceeding 1500 watts (W). Nuclear Regulatory Commission staff (staff) reviewed the application using the guidance in NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material" and Interim Staff Guidance-15, "Materials Evaluation". Based on the statements and representations in the application, as supplemented, staff agrees that these changes do not affect the ability of the package to meet the requirements of 10 CFR Part 71.

1.0 GENERAL INFORMATION

1.1 Packaging Description

The applicant designed the Model No. 2000 package to utilize the following components: two impact limiters, an overpack, a cask body, a new HPI and a new, optional HPI material basket. The impact limiters, the overpack and the cask body remained unchanged. The applicant fabricated the HPI from two concentric stainless steel (SS) cylindrical shells and filled the annulus between the cylindrical shells with depleted uranium (DU). Support discs, arranged axially to provide uniform support, positioned the HPI within the cask cavity. Vertical lifting arms connected the support discs and also served as the primary lifting fixtures. The applicant utilized both a top plug and a bottom plug to close the HPI. The top plug employed a stepped design with DU encapsulated **[[**

]] The applicant also designed the HPI material basket for transporting Cobalt-60 (Co-60) isotope rods.

1.2 Content Description

The applicant designed the Model No. 2000 package to transport Type B quantities of radioactive materials. The applicant requested authorization to transport irradiated hardware (e.g., SS, carbon steels, nickel alloys, and zirconium alloys) as well as byproduct materials (e.g., control rods or control blades composed of hafnium and boron carbide) and specified the minimum decay time for these contents. The applicant also requested authorization to transport Co-60 in the form of pellets or cylindrical solid rods in either normal or special form and identified the peak activity of the Co-60 isotope rods. The applicant stated that Co-60 rods must be shipped in an upright position using the HPI material basket to ensure the contents remain in an analyzed configuration. The applicant specified that all contents shall be in solid form, and that the maximum quantity of material per package, including all cask internals and contents, shall not exceed 5,450 lb.

1.3 Drawings

The packaging drawings identified the nominal dimensions and materials of construction for the impact limiters, the overpack, the cask body, the HPI body and plugs, as well as the HPI material basket.

1.4 Findings

Based on a review of the statements and representations in the application, staff concludes that the package description meets the requirements of 10 CFR Part 71.

2.0 STRUCTURAL

The objective of the structural evaluation is to verify that the structural performance of the package meets the regulatory requirements of 10 CFR Part 71. Staff reviewed applicable codes and standards, material properties, weld design and specification, bolt application, coatings, gamma shielding materials, and seals. Staff also evaluated loss of corrosion resistance and flammable gas generation.

2.1 Description of Structural Design

The applicant designed the Model No. 2000 transportation package to transport Type B quantities of radioactive materials and fissile materials in solid form as well as to protect the radioactive and fissile materials from both normal conditions of transport (NCT) and hypothetical accident conditions (HAC) as required by 10 CFR Part 71. The applicant developed four principal structural components for the Model No. 2000 transportation package: the cask body, the overpack, the HPI, and the HPI material basket.

<u>Cask</u>
As shown on proprietary GEH drawings, the applicant designed the cask body height to be approximately 71.0-inches and the outer diameter to be approximately 38.5-inches. The applicant constructed the cask from two concentric, 1-inch thick SS-304 cylindrical shells. Forgings made of SS-304 connected the cask shell and cavity shell at both the bottom end and the top end of the cask. Lead filled the approximately 4-inch thick annulus between the two shells. The applicant designed the cask cavity to be approximately 26.5-inches in diameter and 54.0-inches deep. The applicant fabricated the cask lid from SS-304 and lead, fully recessed the cask lid into the cask top flange utilizing a stepped design, and secured it to the cask body by fifteen 1¼-inch diameter socket head screws.

<u>Overpack</u>
As shown on proprietary GEH drawings, the applicant constructed the overpack from two 0.5-inch thick SS-304 concentric cylindrical shells which are separated radially by eight equally spaced tubes along the length of the shells as well as by two tube sections around the perimeter of the shells. The applicant attached a toroidal shell impact limiter made of SS-304 to each end of the overpack. The overpack design incorporated an opening just above the lower impact limiter for access to the cask. Fifteen 1⅜-inch diameter shoulder screws joined the top section of the overpack to the base. Aluminum honeycomb impact absorbers, permanently positioned on the inside of the overpack at the top and bottom ends of the cask, provided additional impact

protection.

HPI
As shown on proprietary GEH drawings, the applicant fabricated the HPI, which is used to increase the shielding capability of the package, from two concentric SS cylindrical shells with the following dimensions. DU filled the annulus between the two shells. Support discs both positioned the HPI body within the cask cavity and provided uniform support.

HPI Material Basket
As shown on proprietary GEH drawings, the applicant constructed the basket from **[[ ]]** full-length **[[ ]]** in a **[[ ]]** pattern. The outer **[[ ]]** of the basket formed a **[[ ]]** with the addition of **[[ ]]** welded to adjacent **[[ ]]** with **[[ ]]**.

Staff reviewed the drawings of the Model No. 2000 transportation package on the general assembly drawings provided by the applicant for completeness and accuracy, and finds that the geometry, dimensions, material, components, notes, fabrication details were adequately incorporated throughout the SAR.

2.1.1 Design Criteria

The applicant designed the Model No. 2000 transportation package using design criteria that affect the containment boundary and contribute to the overall structural performance of the package in order to satisfy the 10 CFR Part 71.71 NCT requirements and the 10 CFR Part 71.73 HAC requirements. In addition, the applicant designed the Model No. 2000 transportation package to comply with “General standards for all packages” requirements specified in 10 CFR Part 71.43 and the “Lifting and tie-down standards” requirements specified in 10 CFR Part 71.45. The applicant discussed these criteria in SAR Sections 2.4 through 2.7, and used these criteria to evaluate the structural performance of the Model No. 2000 transportation package.

The applicant evaluated the allowable stress values for NCT Service A Limits and HAC Service Level D Limits based on the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel (B&PV) Code requirements for Section II Level A and D service, and consistent with the Regulatory Guide (RG) 7.6 “Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels,” which provides design criteria based on the ASME B&PV Code, Section III. SAR Tables 2.1-1 and 2.1-2 listed the allowable stresses for various stress categories under NCT and HAC loading conditions for the Model No. 2000 transportation cask, the HPI and the HPI material basket. Staff independently checked the allowable levels, and confirmed that the values are acceptable. Since the load combinations used by the applicant in the Model No. 2000 transportation package structural evaluations were consistent with RG 7.8, “Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Materials,” staff also determined that the load combinations are acceptable.

Based on a review of the design criteria presented in Section 2.1.2 of the SAR, staff finds that the structural design criteria for the Model No. 2000 transportation package are adequate to meet the NCT and HAC requirements of 10 CFR Part 71.

2.1.2 Weights and Centers of Gravity

SAR Table 2.1-3 listed the nominal weights and centers of gravity of the Model No. 2000 transportation package components. The structural evaluations to demonstrate compliance with the 10 CFR Part 71 NCT and HAC requirements utilized these weights.

2.1.3 Identification of Codes and Standards for Package Design

The applicant designed the Model No. 2000 transportation package as a Type B, Category I package in accordance with RG 7.11 and used Codes and Standards for the design of the Model No. 2000 transportation package based on guidance in RG 7.6, which is consistent with ASME B&PV Section III, Subsection NB, as well as NUREG/CR-3854, "Fabrication Criteria for Shipping Containers," for packages transporting Category I contents. Based on the information in NUREG/CR-3854, the applicant fabricated the package containment system in accordance with the ASME Code, Section III, Subsection NB, and evaluated the fabrication, examination, and inspection of the containment boundary components of a Category I package per ASME B&PV Section III, Subsection NB.

Based on a review of the Codes and Standards presented in SAR Section 2.1.4, staff finds that the applicant identified appropriate Codes and Standards for evaluating the structural performance of the Model No. 2000 transportation package under both NCT and HAC loading conditions to determine compliance with the 10 CFR Part 71 regulatory requirements.

2.2 Materials

The licensing drawings and materials specifications in SAR Section 1.3 provided the essential package design details necessary to define its interface dimensions and its physical, structural and shielding characteristics needed to perform the required safety evaluations.

2.2.1 Contents

Staff reviewed the proposed contents for which the applicant requested authorization to transport. Staff determined that the materials used to fabricate the contents preclude significant chemical and corrosion reactions between either the package components or the contents themselves.

2.2.2 Materials Properties

The applicant presented various mechanical properties for SS, carbon steel, aluminum, lead and the O-ring material for different temperatures under NCT and HAC. SAR Tables 2.2-1 through 2.2-9 presented the material properties used in the structural analysis. SAR Section 2.12.1 presented the material properties specific to the impact analyses. Staff determined that the properties complied with the ASME BPVC IID and Metal Handbook. The low temperature fracture properties provided by the applicant also complied with the Metal Handbook and ASME BPVC III. 1. NB-2311. The applicant properly determined the temperature limits of specific materials and components based on their mechanical properties at various temperatures.

The applicant used aluminum to fabricate the cask lid seal retainer. Since aluminum is known to age (i.e., lose strength) when used at temperatures between 300 – 500°F for prolonged time periods (i.e., approximately one year) (The Aluminum Association, Inc., 2003), staff evaluated the aluminum lid seal retainer for a 1500 W heat load under NCT and determined that the strength of degraded aluminum is higher than the applied stress in SAR Table 2.12.4-1. Because the applicant also used aluminum to fabricate the impact limiter, staff also evaluated the aluminum honeycomb crush strength presented on page 9 of SAR reference 2-23 against the degraded strength of this aluminum type (The Aluminum Association, Inc., 2003). Staff determined the aluminum honeycomb strength is well below the degraded aluminum strength. Therefore, staff finds the use of aluminum for the lid seal retainer and the impact limiters acceptable.

The applicant presented the thermal properties used in the Model No. 2000 finite element thermal model. The properties included density, thermal conductivity, specific heat and emissivity at various temperatures. Based on a review of publicly available data (e.g., Metal Handbook), staff determined that the property values are appropriate.

The applicant stated that the O-ring material in the cask lid seal and cask port plugs is the only temperature sensitive material. Staff determined that the current temperatures in the SAR comply with the temperature limits for these components. The applicant asserted that the materials used to fabricate the Model No. 2000 are unaffected by radiation, and identified the O-ring material as the only radiation sensitive cask component. The applicant determined that the O-ring exposure due to the maximum cobalt-60 activity for a one year period is between approximately 100 to 10,000 rad and stated that this amount of exposure will not affect the stability of the O-ring material. Based on a review of publicly available data, staff determined that the materials used to fabricate the Model No. 2000 experience no significant degradation due to irradiation.

2.3 Fabrication and Examination

2.3.1 Fabrication

The applicant stated that Category A and B components for the Model No. 2000 transportation package (cask and overpack) are fabricated in accordance with ASME B&PV Section III, Subsection NB requirements. The applicant also stated that Category B components for both the HPI assembly and the HPI material basket assembly are fabricated in accordance with ASME B&PV Section III, Subsection NF. The applicant further stated that fabrication of package components followed the guidelines presented in NUREG/CR-3854, Fabrication Criteria for Shipping Containers, and that all package components were fabricated in accordance with an NRC approved quality assurance program.

After reviewing NUREG/CR-3854, staff finds the applicant employed acceptable fabrication methods for all Model No. 2000 transportation package containment components and non-containment components.

2.3.2 Examination

The applicant stated that all containment components of the transportation package (cask and overpack) are examined in accordance with ASME B&PV Section III, Subsection NB, while all non-containment components are examined in accordance with ASME B&PV Section III, Subsection NF. The applicant further stated that all package components are examined in accordance with an NRC approved quality assurance program. Staff finds that the applicant described the examination requirements in sufficient detail.

2.4 General Requirements for all Packages

2.4.1 Minimum Packaging Size

The applicant stated in SAR Section 2.4.1 that the smallest dimension of the Model No. 2000 transportation package is approximately 131.5-inches, which is larger than the 71.43(a) requirement of 4.0-inches. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.43(a).

2.4.2 Tamper-Indicating Features

The Model No. 2000 transportation package incorporated a type of lock and wire seal that is installed across the overpack joint section to indicate that an individual tampered with the package. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.43(b).

2.4.3 Positive Closures

The applicant designed the cask of the Model No. 2000 transportation package to be sealed using a gasket and fifteen socket head screws. In addition, the applicant also designed the overpack structure, which is closed by fifteen shoulder bolts, to contain the cask during transport. The applicant specified torque values in the loading process portion of the operating procedures to prevent inadvertent opening of the cask during transport. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.43(c).

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices

The Model No. 2000 transportation package employed a standard ear design for lifting either by crane or by fork truck as well as an auxiliary ear design for lifting by crane only. For both ear designs, the applicant used four bolts to attach the ears to the cask outer shell. The applicant considered three different loading conditions, and calculated maximum induced stresses in the ear. SAR Table 2.5.1-1 provided a summary of the stress evaluation. The table showed that the margins of safety for all lifting ear components are positive indicating that the lifting devices have the minimum required safety factor against the material yield strength. Based on a review of the calculations, staff determined that the analytical results are acceptable. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.45(a).

2.5.2 Tie-Down Devices

The applicant stated that the Model No. 2000 transportation package is normally shipped by truck, and uses eight wire ropes or chains to tie the package to the vehicle. The applicant also stated that the base of the package is wedged to the truck bed to prevent sliding. The applicant calculated the stresses associated with a transport package tied-down to the transport vehicle, as shown in Figure 2.5.2-1, and provided the results in SAR Table 2.5.2-1. The analytical results showed that all tie-down components exhibit a positive margin of safety indicating that the tie-down devices can be operated safely. In addition, based on the results of the analysis, the applicant concluded that either the overpack rib hole will tear out or the connecting weld will fail in shear under excessive loading; however, the applicant asserted that failure of either the rib or the connecting weld does not impair the ability of the overpack or other packaging components to satisfy other regulatory requirements. Staff reviewed the analytical results and determined that the analytical results are acceptable. Based on a review of the analyses and the results, staff finds that the regulatory requirement of 10 CFR Part 71.45(b) is met.

2.6 Normal Conditions of Transport

The Model No. 2000 transportation package structural members shall meet the regulatory requirements of 10 CFR Part 71.71. The applicant analyzed the Model No. 2000 transportation package using the ANSYS finite element (FE) analysis computer program to demonstrate compliance with the 10 CFR Part 71.71 regulatory requirements for NCT.

The applicant developed a three-dimensional, 180° (half symmetry) FE structural model of the Model No. 2000 transportation package to calculate stresses in the structural members of the cask under NCT. The model, which was developed along the vertical plane through the cask center, consisted of the inner and outer shells, flange, top and bottom forgings, lid, and closure bolts, as shown in SAR Figure 2.6.7-1. In the FE analysis, the applicant considered deadweight, internal pressure, and temperature for the NCT loading conditions.

Staff finds that the FE model is adequate to determine stresses under NCT conditions.

2.6.1 Heat

The applicant performed thermal evaluations of the Model No. 2000 transportation package to demonstrate structural adequacy of the package design for the temperatures specified in 10 CFR Part 71.71(c)(1). The applicant provided detailed thermal evaluations and their results in SAR Chapter 3 as well as a brief summary of the thermal analysis in SAR Section 2.6.1.

<u>Summary of Pressure and Temperatures</u>: In evaluating the structural performance of the Model No. 2000 transportation package under NCT, the applicant considered both pressure and temperature. SAR Chapter 3 presented the maximum normal operating pressure evaluation as well as the maximum component temperature evaluation for NCT. Using the maximum design allowable internal pressure of 30 psia, the applicant evaluated the package structural performance. SAR Tables 2.6.1-1 and 3.3.1-1 listed the maximum temperatures calculated for various package components based on an initial ambient air temperature of 100°F and a maximum internal power generation of 3000 W.

<u>Differential Thermal Expansion</u>: The applicant considered temperature dependent material properties of the cask components to calculate radial and longitudinal expansions in the cask, the HPI, and the HPI material basket. SAR Tables 2.6.1-2 and 2.6.1-3 provided the calculation results for the radial and longitudinal expansions. The applicant concluded that the thermal expansions of the cask, HPI and HPI material basket are not a concern. Staff reviewed the calculations, and finds the results of the analysis acceptable.

<u>Stress Calculations</u>: The applicant provided the stress calculation results in SAR Section 2.6.7. Using the ANSYS FE model, the applicant calculated stresses for the Model No. 2000 package under combined pressure and thermal loading conditions per the guidance in RG 7.8.

<u>Comparison with Allowable Stresses</u>: The applicant provided a comparison study between the calculated stress intensities and the material allowable limits for the NCT conditions in SAR Table 2.6.1-5. The comparison study showed that the margins of safety are all positive and

therefore acceptable. Based on a review of the applicant's analytical methods and results, staff finds that the application meets the regulatory requirements of 10 CFR Part 71.71(c)(1).

2.6.2 Cold

The applicant performed a thermal evaluation for the Model No. 2000 transportation package per RG 7.8 to demonstrate the structural adequacy of the package design for a temperature of -40°F in still air and shade as specified in 10 CFR Part 71.71(c)(2). The applicant provided the thermal evaluation results under cold conditions in SAR Table 2.6.1-4. The evaluation results showed that the calculated margins of safety are all positive and that the Model No. 2000 transport package component temperatures are maintained within their safe operating ranges for all NCT. After reviewing the results, staff finds that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.71(c)(2).

2.6.3 Reduced External Pressure

Although 10 CFR Part 71.71(c)(3) requires that the package be subjected to a reduced external pressure of 3.5 psia, the applicant stated that the effect of a reduced external pressure of 3.5 psia is considered negligible for the Model No. 2000 transportation package. The applicant concluded this based on the NCT structural analyses presented in SAR Section 2.6.7 where it demonstrated the structural integrity of the Model No. 2000 transportation package under a 30 psia internal design pressure during NCT. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.71(c)(3).

2.6.4 Increased External Pressure

Although 10 CFR Part 71.71(c)(4) requires that the package be subjected to an external pressure of 20 psia, the applicant stated that the effect of an external pressure of 20 psia is considered negligible for the Model No. 2000 transportation package because of the thick outer shell and end closures. The applicant concluded this based on the NCT structural analyses presented in SAR Section 2.6.7 which demonstrated the structural integrity of the Model No. 2000 transportation package under many different loading cases which exceeded the external pressure requirement. Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.71(c)(4).

2.6.5 Vibration

The applicant stated that the effects of shock and vibration are considered negligible for the Model No. 2000 transportation package because (i) the closure system is designed in accordance with NUREG/CR-6007, "Stress Analysis of Closure Bolts for Shipping Casks, " which determines the bolt preload based on the impact loads experienced during HAC which bound the loads experienced during transport, (ii) the cask has been structurally analyzed using the NCT accelerations (i.e., 14.6 g, 15.5 g and 55.1 g) to produce the maximum stress intensity in the package components, (iii) the results of the cask body, the HPI and the HPI material basket analyses show that the package is capable of experiencing continuous NCT accelerations without degrading the ability of the package to meet the regulations, and (iv) based on a fatigue analysis per ASME Code, Section III, NB, all bolts shall be replaced after 190 transports. Staff reviewed the evaluation, and found it acceptable. Staff finds that the regulatory requirements of 10 CFR Part 71.71(c)(5) for normal vibration incidents and shock loading conditions during transportation are met.

2.6.6 Water Spray

Although 10 CFR Part 71.71(c)(6) requires that the package be subjected to a water spray test that simulates exposure to rainfall of approximately 2 inches/hour for at least 1 hour, the applicant fabricated the Model No. 2000 transportation packaging outer layer entirely with SS making the water spray test not applicable since the water spray test is primarily intended for packaging relying on material that either absorb water, are softened by water, or are bonded by water soluble glue. Staff finds that the application satisfies the regulatory requirements of 10 CFR Part 71.71(c)(6).

2.6.7 NCT Free Drop

The applicant evaluated the Model No. 2000 transportation package to meet the free drop requirements of 10 CFR Part 71.71 by a combination of FE analyses and classical hand calculations. Considering two drop orientations (end and side drops) in the analyses, the applicant evaluated a drop height of 1-foot onto a flat, essentially unyielding horizontal surface.

2.6.7.1 Cask Stress Analysis

<u>End Drop</u>: The applicant identified the two most critically stressed regions as the cask flange region and the cask lid in the closure bolt contact region. The applicant evaluated the regions and provided the stress results. Per the criteria presented in RG 7.6 for the flange region, SAR Table 2.6.7-3 documented the following stresses: the primary membrane, the primary membrane plus primary bending, and the primary membrane plus primary bending plus secondary stress. The applicant compared the stress results to the allowable stress at a bounding temperature of 300°F and found that the calculated margins of safety are all positive. Also, SAR Table 2.6.7-5 documented the stress combinations in accordance with the RG 7.6 criteria for the cask lid in the closure bolt contact region. The results showed that the calculated margins of safety are all positive. Because all of the margins of safety are positive, the applicant concluded that the Model No. 2000 cask meets the end drop requirement of 10 CFR Part 71.71(c)(7). Staff reviewed the analysis, and found them acceptable.

<u>Side Drop</u>: The applicant evaluated the NCT side free drop using the same FE model which was used for the end drop case and presented the results in SAR Table 2.6.7-11. For each category in the table, the applicant showed that the margin of safety is positive when compared with the stress intensity. Staff reviewed the analysis, and found the results acceptable.

2.6.7.2 HPI Stress Analysis

<u>End Drop</u>: Using the ANSYS FE analysis program, the applicant evaluated the HPI NCT end drop. SAR Table 2.6.7-17 documented the primary membrane and primary membrane plus primary bending stresses, and compared them to the stress criteria in ASME Section III-NF. The applicant determined the calculated margins of safety to be positive. Staff reviewed the analysis, and found the results acceptable.

<u>Side Drop</u>: The applicant evaluated the HPI NCT side free drop using the same FE model which was used for the HPI end drop case and presented the stress results in SAR Tables 2.6.7-14 and 2.6.7-16. As shown in the tables, the applicant calculated positive margins of safety when compared with the stress intensity for each category. Staff reviewed the analysis, and found the results acceptable.

2.6.7.3 HPI Material Basket Stress Analysis

End Drop: The applicant stated that the HPI material basket NCT end drop was evaluated using classical hand calculations. The applicant evaluated the worst-case condition of an end drop inertia load of 15.5 g in the calculations. From this calculation, the applicant determined the maximum membrane stress was 837 psi which resulted in a positive margin of safety of 19.2. Staff reviewed the analysis, and found them acceptable.

Side Drop: The applicant evaluated the HPI material basket NCT side free drop using the same classical hand calculations used for the basket end drop case. Using the NCT side drop inertia load of 55.1 g, the applicant calculated the maximum bending stress to be 688.4 psi and the shear stress to be 9,540 psi. The applicant calculated a stress intensity of 1641.0 psi for the basket using a combination of the bending and shear stresses. Using this stress intensity, the applicant calculated a positive margin of safety of 13.5. Staff reviewed the analysis, and found them acceptable. Staff finds that the Model No. 2000 transportation package meets the regulatory requirements of 10 CFR Part 71.71(c)(7).

2.6.8 Corner Drop

The applicant stated that the corner drop analysis is not applicable to the Model No. 2000 transportation package because (i) the Model No. 2000 transportation package is composed of materials other than fiberboard or wood, and (ii) the weight of the Model No. 2000 transportation package exceeds 220 lb. Staff determined that the corner drop test is not applicable to the Model No. 2000 transportation package, and finds that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.71(c)(8).

2.6.9 Compression

The applicant stated that the compression test is not applicable to the Model No. 2000 transportation package because the package weight is greater than 11,000 lb. Staff determined that the compression test is not applicable to the Model No. 2000 transportation package, and the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.71(c)(9).

2.6.10 Penetration

Although 10 CFR Part 71.71(c)(10) requires that impact of a vertical steel cylinder with a hemispherical end of 1.25-inches diameter and a 13 lb mass dropped from a height of 40-inches onto the exposed surface of the package that is expected to be most vulnerable to puncture, the applicant stated that a penetration evaluation was not performed per the RG 7.8 guidance because the Model No. 2000 cask has no unprotected valves or rupture discs that could be affected by the NCT. Staff determined that the applicant's statement is acceptable, and finds that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.71(c)(10).

2.7 Hypothetical Accident Conditions

The applicant evaluated the Model No. 2000 transportation package for HAC of free drop, crush, puncture, thermal, and water immersion as required by 10 CFR Part 71.73. The applicant analyzed the Model No. 2000 transportation package using the ANSYS FE analysis computer program, impact analyses and classic calculations to demonstrate compliance with the 10 CFR Part 71.73 regulatory requirements for HAC. The applicant used the same 180° ANSYS FE model employed for the NCT analyses.

2.7.1 Free Drop

Paragraph 71.73(c)(1) of 10 CFR Part 71 requires that the structural adequacy of a cask be demonstrated by a free drop through a distance of 30 ft. onto a flat, unyielding, horizontal surface in a position for which maximum damage is expected. In order to determine the orientation that produces the maximum damage, the applicant evaluated the Model No. 2000 transportation cask for impact orientations in which the cask strikes the impact surface on its bottom end and side.

2.7.1.1 Cask Stress Analysis

End Drop: The applicant identified the two most critically stressed regions as the cask flange region and the cask lid in the closure bolt contact region. SAR Table 2.7.1-3 documented the primary membrane and primary membrane plus primary bending stresses per the criteria presented in RG 7.6 for the flange region. Comparing the stress results to the allowable stresses at a bounding temperature of 300°F, the applicant showed that the calculated margins of safety are all positive. Also, in SAR Table 2.7.1-5, the applicant documented the stress combinations in accordance with the RG 7.6 criteria for the cask lid in the closure bolt contact region, and showed that the calculated margins of safety are all positive. Staff reviewed the analysis, and found them acceptable.

Side Drop: The applicant evaluated the HAC side free drop using the same finite element model which was used for the NCT end drop case, and presented the analytical stress results in SAR Tables 2.7.1-7 and 2.7.1-9. For each category, the applicant showed that the margin of safety is positive when compared with the stress intensity. Staff reviewed the analysis, and found them acceptable.

2.7.1.2 HPI Stress Analysis

End Drop: Using the ANSYS FE analysis program, the applicant evaluated the HPI HAC end drop. SAR Table 2.7.1-10 documented the primary membrane and primary membrane plus primary bending stresses, and compared them to the stress criteria in ASME Section III, Appendix F. SAR Table 2.7.1-10 demonstrated that the calculated margins of safety are all positive. Staff reviewed the analysis, and found them acceptable.

Side Drop: The applicant evaluated the HPI HAC side free drop using the same FE model which was used for the HPI NCT end drop case, and presented the results in SAR Tables 2.7.1-11 through 2.7.1-14. As shown in the tables, the applicant calculated a positive margin of safety when compared with the stress intensity for each category. Staff reviewed the analysis, and found them acceptable.

2.7.1.3 HPI Material Basket Stress Analysis

End Drop: The applicant evaluated the HPI material basket HAC end drop using classical hand calculations. Using the HAC end drop inertia load of 157.5 g in the calculations, the applicant evaluated the worst-case condition of an upright end drop, and calculated the maximum membrane stress to be 8,505 psi. The applicant compared this stress to the criteria in SAR Table 2.1-2. In addition, the applicant evaluated the basket elastic stability for the HAC end drop condition. The applicant modeled the basket as a column with pinned ends, and evaluated the basket using the Euler equation for buckling. The applicant calculated a critical load for the HPI material basket of 55,530,000 lbs, and divided this critical load by the HPI material basket weight of 49,927.5 lbs to calculate a positive factor of safety of 1112.2. The result of this calculation demonstrated that the basket elastic stability of the basket is not a concern during the HAC end drop conditions. Staff reviewed the hand calculations, and found them acceptable.

Side Drop: The applicant evaluated the HPI material basket HAC side free drop using the same classical hand calculations used for the basket end drop case. Using the HAC side drop inertia load of 161.9 g, the applicant calculated the maximum bending stress to be 2,023 psi and the shear stress to be 29,736 psi. The applicant calculated a stress intensity of 4,822 psi for the basket using a combination of the bending and shear stresses, and used this stress intensity in determining a positive margin of safety of 6.4. Staff reviewed the analysis, and found them acceptable.

Staff finds that the Model No. 2000 transportation package meets the regulatory requirements of 10 CFR Part 71.73(c)(1).

2.7.2 Crush

Although 10 CFR Part 71.73(c)(2) requires a dynamic crush test when the specimen has a mass not greater than 1,100 lb and an overall density not greater than 62.4 pounds per cubic foot based on external dimensions, the applicant stated that the crush test specified in 71.73(c)(2) is not required for the Model No. 2000 transportation package since the weight of the Model No. 2000 transportation package exceeds 1,100 lb. Staff verified that the Model No. 2000 transportation package weighs more than 1,100 lb and has an overall density greater than 62.4 pounds per cubic foot. Staff finds that the application satisfies the regulatory requirements of 10 CFR Part 71.73(c)(2).

2.7.3 Puncture

Paragraph 71.73(c)(3) of 10 CFR Part 71 requires that a free drop of the specimen, through a distance of 40-inches in a position for which maximum damage is expected, be performed onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 6-inches in diameter, with the top horizontal and its edge rounded to a radius of not more than 0.25-inch, and of a length as to cause maximum damage to the package, but not less than 8-inches long. The long axis of the bar must be vertical.

The applicant evaluated the puncture performance of the Model No. 2000 transportation package using the LS-DYNA FE analysis computer program. SAR Table 2.12.1-6 presented two drop configurations (end and side pin punctures), and SAR Figures 2.12.1.11-57 and 2.12.1.11-58 showed strain contours of the package after 30-foot end drop and side drop punctures, respectively. The analysis showed that the maximum strain is 39%, but a review of the results found that the maximum strain is limited to local deformation of the overpack. The analysis also showed that gross deformations of the cask are not expected because the maximum strain in the outer shell of the cask is 31% and limited to the puncture area. The applicant stated that the results of the combined 30-foot impact and pin puncture will be used as input for the HAC thermal evaluation.

Based on a review of the analytical results, staff finds that the application meets the regulatory requirements of 10 CFR Part 71.73(c)(3).

2.7.4 Thermal

Paragraph 71.73(c)(4) of 10 CFR Part 71 requires exposure of the package with an average flame temperature of at least 1,475°F for a period of 30 minutes. The applicant performed thermal evaluations of the cask body under HAC, and presented the evaluation findings in SAR Chapter 3. Staff's detailed safety evaluations on the applicant's thermal evaluations are provided in Chapter 3 of this SER. The following evaluation is based on a brief summary of the applicant's thermal evaluations provided in SAR Section 2.7.4.

<u>Summary of Pressure and Temperatures</u>: The applicant used the ANSYS FE computer program to estimate temperatures and pressures of the cask components under HAC. SAR Table 2.7.1-16 provided a summary of temperatures for the Model No. 2000 transportation package for HAC. During HAC, the average temperature of the cask fill gas peaked at 585°F at 11 hours after the end of the 30-minute fire. The cask internal pressure from gas expansion was 29.0 psia, which is less than the design pressure of 30 psia.

<u>Differential Thermal Expansion</u>: The applicant evaluated thermal expansion of the Model No. 2000 transportation package under the HAC fire accident by applying a 300°F temperature differential between the outer surface of the cask and the inner surface of the cask as discussed in SAR Section 2.6.7. The applicant also evaluated thermal expansion of the closure bolts using the temperatures associated with the HAC fire and discussed the results in SAR Section 2.12.4.

<u>Stress Calculation</u>: The applicant calculated the cask body pressure stresses under the HAC fire accident condition. The applicant evaluated the Model No. 2000 transportation package by uniformly applying the 30 psia design pressure on the cask internal surfaces in combination with the mechanical loads presented in SAR Section 2.7.1.

<u>Comparison with Allowable Stresses</u>: The applicant provided the combined HAC pressure and mechanical stresses in SAR Table 2.7.4-1, where the primary membrane, primary membrane plus primary bending stresses were calculated in accordance with the criteria presented in RG 7.6. For each category, the applicant calculated a positive margin of safety when the allowable stress was compared to the stress intensity. Based on the evaluation results, the applicant concluded that the10 CFR Part 71.73(c)(4) requirement was satisfied. Staff reviewed the applicant's calculations and the results. Because all the calculated margins of safety were positive, staff found the results acceptable.

Based on a review and confirmation of the applicant's analytical methods and results, staff finds that the Model No. 2000 transportation package meets the regulatory requirements of 10 CFR Part 71.73(c)(4).

2.7.5 Immersion – Fissile Material

As indicated in their response to staff's request for additional information, the applicant chose not to include fissile material, either in the form of irradiated fuel rods or special nuclear material, as authorized content (ADAMS Accession No. ML17164A287). Therefore, staff determined that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.73(c)(5).

2.7.6 Immersion – All Packages

Although 10 CFR Part 71.73(c)(6) requires that a separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 50 ft. (equivalent pressure of 21.7 psig) for a period of 8 hours, the applicant stated that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.73(c)(6) because (i) both the cask closure the lid and bolts are designed to survive puncture loads which exceed the load experienced during immersion, and (ii) from ASME Section III-NB, A-2221, the 1.0-inch thick outer shell of the cask, which has a mean radius of 18.75-inches, produces a primary membrane stress intensity of 418 psi at 21.7 psig, which is much less than the material yield strength. Staff finds the applicant's statement acceptable that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.73(c)(6).

2.7.7 Deep Water Immersion Test for Type B package containing more than 10^5 A_2

Although 10 CFR Part 71.61 requires that a Type B package containing more than 10^5 A_2 must be designed so that its undamaged containment system can withstand an external water pressure of 290 psig for a period of not less than 1 hour without collapse, buckling, or in-leakage of water, the applicant stated that the HAC deep water immersion test for the Model No. 2000 transportation package is not applicable because the contents specified in this application contain less than 10^5 A_2. Staff finds that the Model No. 2000 transportation package satisfies the regulatory requirements of 10 CFR Part 71.61.

2.7.8 Summary of Damage

The applicant stated in SAR Section 2.7.8 that the results of the analyses and tests reported in SAR Sections 2.7.1 through 2.7.7 demonstrated that the damage incurred by the Model No. 2000 transportation package during HAC does not diminish the integrity of the containment boundary. The applicant also stated that, although a 30-feet side drop followed by a 40-inch pin puncture accident may damage the overpack and inflict local damage on the outer shell of the cask, the shielding remained intact and satisfied the accident shielding criteria.

Based on the assessments mentioned above, the applicant concluded that the Model No. 2000 transportation package can safely withstand the HAC free drop, puncture and fire test performed in sequence. Staff reviewed the evaluations and their results presented in SAR Section 2.7.1 through 2.7.7, and finds the damage assessments by the applicant acceptable.

Staff finds that the application meets the regulatory requirements of 10 CFR Part 71.73.

2.8 Evaluation Findings

Based on a review of the statements and representations in the application, staff concludes that the Model No. 2000 transportation package is adequately described and evaluated to demonstrate that its structural capabilities meet the regulatory requirements of 10 CFR Part 71.

2.9 References

F. Farrell. “Assessment of Aluminum Structural Materials for Service within ANS Reflector Vessel.” ORNL/TM-13049. Oak Ridge National Laboratory. 1995.

3.0 THERMAL EVALUATION

The applicant submitted an amendment request of CoC 9228. The amendment requested to add a HPI, remove contents and modify contents for the model Model No. 2000 package. The consolidated SAR is designated as NEDE-33866P. The objective of this review is to verify that the package design and performance, with these requested changes, still satisfy the thermal requirements of 10 CFR Part 71 under both NCT and HAC.

3.1 Thermal Design

The applicant stated in Section 3.1.1, “Design Features,” of the SAR that the Model No. 2000 package is a thermally passive system, and that the canister is enclosed in an overpack which serves as a fire shield. The applicant designed the overpack to reduce heat flow from the HAC fire environment into the package using enclosed air spaces. In addition to using lead shielding on the top and sides of the package, the Model No. 2000 employed a SS forging at the package base. The applicant intended that the SS forging function as a heat sink to allow heat to flow through the bottom of the package.

The applicant based the lid seal design on a 1500 W content decay heat. The lid seal configuration used a metal retainer with four O-rings which have a service limit between -40 and approximately 400°F. The applicant placed two of the O-rings on top of the metal retainer and two O-rings on the bottom of the metal retainer. For each port, the applicant utilized a pipe plug, which has a service temperature limit of 612°F, as the containment component. Staff reviewed SAR Sections 1.2, “Package Description,” and Section 3.1, “Description of Thermal Design,” and finds that the Model No. 2000 package thermal design is well described.

3.2 Material Properties and Component Specifications

The applicant provided the packaging component thermal properties in SAR Section 3.2 and SAR Tables 3.2.1-1 and 3.2.1-2. The Model No. 2000 packaging component materials included SS, lead, and aluminum. The applicant provided the maximum allowable temperatures of the package components in SAR Table 3.1.3-1. Staff reviewed the material properties and component specifications provided in SAR Section 3.2 and finds the material properties and component specifications acceptable for the Model No. 2000 thermal evaluations.

3.3 NCT Thermal Evaluation

The applicant described the NCT thermal analysis in SAR Section 3.3, "Thermal Evaluation under Normal Conditions of Transport." For the NCT thermal analysis, the applicant assumed that both the cask and the HPI are backfilled with helium at 70°F and 14.7 psia. Although the applicant neglected natural convection within the package cavity, the applicant modeled natural convection from the package surfaces to the 100°F environment. In addition, the applicant modeled radiation heat transfer assuming a radiation emissivity of 0.22 for the package surfaces under NCT. The applicant also applied insolation directly to the package surface per 10 CFR Part 71.71, and performed the NCT thermal evaluation without insolation to address the 10 CFR Part 71.43(g) requirement to evaluate the package surface temperature in the shade.

Staff reviewed the model description, the heat transfer conditions between the package and the environment, heat generation by the contents and solar heat flux described in SAR Section 3.3. Staff determined that the NCT thermal evaluation, as described by the applicant, is consistent with the recommendations of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material"; therefore, it is acceptable to staff.

3.3.1 Heat and Cold

The applicant provided the component temperatures for a heat load of 1500 W at an ambient temperatures of 100°F in shade and with insolation in Table 3.5.1-1 of SAR Section 3.5.1.2 "NCT Temperature Results." In SAR Table 3.5.1-1, the applicant showed that the maximum lid seal temperature is 317°F and the maximum port seal/pipe plug temperature, which occurred at the vent port, is 323°F with insolation. In SAR Table 3.5.1-3, the applicant showed that both of these temperatures are below their respective allowable limits of 400°F and 612°F. The applicant also showed in SAR Table 3.5.1-1 that the maximum honeycomb impact limiter temperature is 272°F and the maximum lead shielding temperature is 327°F. In SAR Table 3.5.1-3, the applicant showed that these temperatures are below their allowable limits of 350°F and 622°F respectively. Based upon the lead shielding temperatures, the applicant asserted that the lead does not melt under NCT.

Prior to restricting the contents such that the heat load did not exceed 1500 W, the applicant calculated an average fill gas temperature of 505°F for the HPI and the cask combined at a heat load of 3000 W. Using this temperature, the applicant calculated a maximum normal operating pressure of 26.8 psia which is bounded by the maximum design internal pressure of 30.0 psia, as shown in SAR Table 3.1.4-1.

Staff reviewed the initial conditions, boundary conditions and thermal-model descriptions in SAR Section 3.3 as well as the NCT temperature results shown in SAR Tables 3.5.1-1, 3.5.1-3 and 3.5.1-6. Staff noted that both package component temperatures and the cavity gas pressure are below the allowable limits. Staff also confirmed that the package body is well below its service limits for NCT and meets the thermal requirements of 10 CFR 71.71(c)(1).

The applicant provided the component temperatures at ambient temperatures of -40°F and -20°F in shade in Table 3.5.1-2 of SAR Section 3.5.1.2. After reviewing the cold condition temperatures of the lid O-ring seals as well as the pipe plugs and O-rings located at the vent port, drain port and test port, staff determined that these components remain within their service range. Staff confirmed that the Model No. 2000 package meets the thermal requirements of 10 CFR 71.71(c)(2).

3.3.2 Thermal Contact Resistance

The applicant explained in SAR Section 3.3 that the ANSYS computer code modeled thermal contact as thermal contact conductance (TCC) which is defined as the reciprocal of the thermal contact resistance. A high TCC value implied low thermal contact resistance and a low TCC value implied high thermal contact resistance. The applicant provided typical thermal contact conductive values from open literature in SAR Table 3.3-1. The applicant used the data in Table 3.3-1 to develop five TCC levels for use in the thermal model. The applicant listed the five TCC levels, which ranged from low to high resistance, in SAR Table 3.3-2, and then assigned thermal contact resistance levels to the modeled contact elements. SAR Table 3.3-3 showed the thermal contact resistance levels assigned to the modeled contact elements.

The applicant performed a sensitivity study and compared the NCT temperature results with insolation generated using mixed contact resistance versus NCT temperature results with insolation generated using perfect contact in SAR Table 3.5.1-6. The applicant concluded in SAR Section 3.3.1.1.4, “NCT Thermal Contact Resistance Sensitivity Study,” that the analysis using mixed thermal contact resistances between components results in higher package temperatures because mixed thermal contact resistances impede the decay heat from leaving the package.

Staff reviewed Sections 3.3 and 3.4.1.1.4. Staff also reviewed Table 3.5.1-6 which compared the NCT temperatures generated using both mixed and perfect thermal contact resistances for a heat load of 1500 watts with insolation. Although the temperatures generated with mixed contact resistances are similar to the temperatures generated with perfect contact resistance, staff finds the Model No. 2000 package is acceptable because the peak NCT component temperatures generated with perfect contact are below the NCT allowable limits.

3.4 Thermal Evaluation under HAC

3.4.1 Initial Conditions and Boundary Conditions

As described in SAR Section 3.4, “Thermal Evaluation under Hypothetical Accident Conditions,” the applicant modeled the package in a horizontal orientation. In the model, the applicant included damage consistent with a 30-foot side drop and a 40-inch drop onto a 6-inch diameter pin. The applicant used emissivity values of 0.9 during the 30-minute fire 1475°F (800°C) and 0.8 during the post-fire cooldown. The applicant applied natural convection heat transfer coefficients both prior to and after the 30-minute fire as well as a forced convection heat transfer coefficient during the 30-minute fire. The applicant assumed that the package is exposed to the NCT with solar insolation both prior to and following the 30-minute fire. The applicant provided the HAC thermal evaluation results in SAR Section 3.5.1.3, “HAC Temperature Results.”

Staff reviewed the initial conditions, boundary conditions and thermal model described in SAR Section 3.4 and the HAC temperature results with a heat load of 1500 W in Tables 3.5.1-4, 3.5.1-5, and 3.5.1-7 in SAR Section 3.5.1.3. Staff determined that the applicant’s HAC model is acceptable and consistent with the NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material.”

3.4.2 Thermal Contact Resistance for HAC

The applicant stated in SAR Section 3.4.1.1, “Additional Thermal Contact for the Hypothetical Accident Condition,” that when oriented on its side, the contact between the material basket disks and HPI inner shell, between the HPI disks and cask cavity shell, between the cask shell and overpack inner shell, and between the overpack inner and outer shells are modeled with a “Low/Moderate” thermal contact resistance (thermal contact conductance of 15.0 Btu/h-in^2-°F) as shown in SAR Figure 3.4.1-2. The applicant chose a “Low/Moderate” thermal contact resistance for these contact elements in order to maximize the heat from the contents and the HAC fire into the package shield at the puncture location.

Staff reviewed SAR Section 3.4.1.1 and compared the peak temperatures calculated with both mixed and perfect thermal contact resistances shown in SAR Table 3.5.1-7 for HAC with insolation for a heat load of 1500 W. Staff found that, although some perfect contact resistance peak temperatures exceeded the mixed contact resistance peak temperatures, most remained below the values calculated with mixed contact resistances. Staff also determined that all calculated HAC peak component temperatures are below the HAC allowable limits when using either mixed or perfect contact resistances.

3.4.3 Maximum Temperatures and Pressure

The applicant provided the maximum calculated component temperatures in SAR Section 3.5.1.3, “HAC Temperature Results,” and SAR Tables 3.5.1-4, 3.5.1-5 and 3.5.1-7. Using a heat load of 3000 W, the applicant calculated an average fill gas temperature of 585°F for the HPI and the cask combined. Using this temperature, the applicant predicted an HAC maximum pressure of 29.0 psia as stated in SAR Section 3.4.3.2, “HAC Maximum Pressure Calculation.”

Staff reviewed the HAC temperature results in SAR Section 3.5.1.3 and SAR Tables 3.5.1-4, 3.5.1-5 and 3.5.1-7, including thermal analysis results using both mixed and perfect thermal contacts among packaging components. Staff confirmed that the maximum HAC pressure of 29.0 psia is below the design limit of 30 psia and that the maximum HAC temperatures of the package components, including the lid, drain port and vent port seals, are well below their service limits under HAC in compliance with 10 CFR 71.73(c)(4).

3.5 Findings

Based on review, the staff finds that the thermal design features are adequately described and evaluated, the thermal analyses are discussed and described in sufficient detail for verification of NCT and HAC, and the component temperatures and cavity pressures of the Model No. 2000 fall within the limits of both NCT and HAC for a heat load limit of 1500 W. The staff finds that, with a heat load limit of 1500 watts, the Model No. 2000 package meets the thermal requirements, in compliance with 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

The applicant submitted an amendment request of CoC No. 9228. The amendment requested to add a HPI, remove contents and modify contents for the model Model No. 2000 package. The applicant submitted a consolidated SAR which is designated as NEDE-33866P. The objective of this review is to verify that the containment design and performance, with these requested changes, still satisfy the containment requirements of 10 CFR Part 71 under NCT and HAC.

4.1 Containment System Description

The applicant stated in SAR Section 4.1, “Description of Containment System,” that the containment system is defined by the containment vessel, closure lid, vent, drain, and test ports and containment welds as shown in SAR Figure 4.1.3-1. The applicant specified that leakage rate tests be performed on the entire containment boundary, including containment welds and base metals, during fabrication, maintenance, and periodically as defined in SAR Section 8.0, “Acceptance Tests and Maintenance Program.”

The applicant stated in SAR Section 4.1 that the containment vessel is constructed of a steel-clad lead cylinder with a stainless-steel forging at each end. Screws connected the closure lid to the containment vessel. The vent port and drain ports provided the ability to eliminate water collected during underwater operations from the package cavity, and the test port provided the ability to test the closure lid seal adequacy after each loading operation. To ensure structural and containment integrity, the applicant utilized **[[ ]]** for all welds. The applicant also liquid penetrant tested each weld after both the root and final passes. In addition, the applicant helium leak tested welds as described in SAR Section 8.

The applicant stated in SAR Section 4.1.3.2, “Cask Lid Closure Seal,” that O-rings, in conjunction with a metal retainer, are used to seal the Model No. 2000 for shipments of contents having 1500 W decay heat. The applicant chose O-rings with a service temperature range between -40 and approximately 400°F. The applicant stated in SAR Section 4.1.3.3, “Cask Port Seals,” that the containment boundary for each port is the respective pipe plug of each port. The applicant chose pipe plugs which are designed for leaktightness and which have a service limit of 612°F. The applicant designed the Model No. 2000 with both the port covers and the port cover O-rings outside the containment boundary.

Based on a review of the statements and representations in the application, staff determined that the containment system description and the leakage rate test applied to the entire containment boundary, including base metals, containment welds, and pipe plugs are adequate.

4.2 Containment under Normal Conditions of Transport

The applicant stated in SAR Section 4.2, “Containment under Normal Conditions of Transport”, that the Model No. 2000 package containment is designed to prevent release of radioactive materials under NCT, to prevent any significant increase in external radiation and to prevent a reduction in package containment effectiveness. The applicant also stated in SAR Section 4.2 that the maximum average fill gas temperature is 349°F for a 1500 W heat load under NCT. At this temperature, the applicant calculated a maximum package gas pressure of 22.4 psia which is below the design pressure of 30.0 psia. The applicant also calculated a maximum lid seal temperature of 317°F which is bounded by the operational limit of 400°F for the lid seal. For the vent, drain, and test ports, the applicant determined that the maximum temperature is 323°F which is below the allowable limit of 612°F. In addition, the applicant stated in Section 4.2 of the SAR that both O-rings are within their operational limits and that containment integrity is maintained under NCT.

Staff reviewed the package containment configuration in SAR Section 4.2 and the thermal evaluation in SAR Section 3.5.1.2, “NCT Temperature Results”. Staff confirmed that both the maximum package gas pressure and peak seal temperatures are below their respective limits. Staff confirmed that the Model No. 2000 package meets the NCT containment requirements in 10 CFR Part 71.71 and 71.51(a)(1).

4.3 Containment under Hypothetical Accident Conditions

The applicant stated in SAR Section 4.3, “Containment Under Hypothetical Accident Conditions”, that the maximum average fill gas temperature is 421°F for a 1500 W heat load under HAC. At this temperature, the applicant calculated a maximum package gas pressure of 24.4 psia which is below the design pressure of 30.0 psia. The applicant also calculated a maximum lid seal temperature of 389°F which is bounded by the operational temperature limit of 400°F. The applicant determined that the maximum vent port temperature is 392°F which is bounded by the allowable limit of 612°F. The applicant also determined that the maximum seal temperatures at the drain and test ports are 537°F and 515°F respectively. Although the maximum seal temperatures for the drain and test ports exceed the operational limit of 400°F, the applicant indicated that they are still below the allowable seal material temperature limit of 612°F. The applicant identified in SAR Table 3.5.1-4 that the duration of HAC maximum temperatures at these ports is less than 1 hour. The applicant indicated that minimal seal material degradation resulted from the seals remaining at these temperature for these short time periods. The applicant also stated in SAR Section 4.3 that the O-ring seals located at the drain and test ports are outside of the pipe plug, which has a limit of 612°F, that is part of the containment boundary.

Staff reviewed the package containment configuration in SAR Section 4.3 and the thermal evaluation in SAR Section 3.5.1.3. Staff confirmed that both the maximum package gas pressure and the peak temperatures for all containment boundary components are below their respective limits. Staff confirmed that the Model No. 2000 package meets the HAC containment requirements 10 CFR Part 71.73 and 71.51(a)(2).

4.4 Leakage Rate Tests

The applicant stated in SAR Section 4.4, “Leakage Rate Tests for Type B Packages”, that the pre-shipment, fabrication, maintenance and periodic leakage rate tests are performed on the Model No. 2000 in accordance with ANSI N14.5 - 1997. The applicant required that an ASNT certified Level III examiner develop all leak testing procedures for leak testing of the Model No. 2000 package.

Staff reviewed SAR Sections 4.0, 7.0 and 8.0. Staff accepted the leakage rate testing descriptions, and confirmed that the fabrication, maintenance, and periodic leakage rate tests will be performed on the entire containment boundary of the Model No. 2000 package in accordance with ANSI N14.5 – 1997. Staff also confirmed that all pre-shipment, periodic, maintenance and fabrication leak testing procedures are developed by an ASNT Level III examiner per ASNT requirements in accordance with ANSI N14.5 – 1997.

4.5 Findings

Staff reviewed the Model No. 2000 package containment system descriptions in the SAR. Staff concluded that the Model No. 2000 package descriptions and evaluations demonstrate that the package satisfies the containment requirements of 10 CFR Part 71, and that the package is leak-tight and that the package meets the containment requirements of 10 CFR 71.51(a)(1) for NCT and 10 CFR 71.51(a)(2) for HAC.

5.0 SHIELDING EVALUATION

The applicant submitted a request for renewal of CoC 71-9228 for the Model No. 2000 transportation package with modified contents and packaging design. The allowable contents requested by the applicant as part of this amendment included (1) irradiated hardware and byproducts, and (2) Co-60 isotope rods. The applicant also modified the package design by adding a new package insert called the HPI, which is required for all authorized contents, and by performing shielding evaluations for each specific content. In addition, the applicant added a new material basket designed specifically for the shipment of the Co-60 contents. Staff approved the limited use of this insert in a letter authorization dated February 11, 2016 (ADAMS Accession No. ML16043A018). In addition, the applicant consolidated the SAR and removed some package authorized contents described in two SARs prior to this consolidated SAR.

Staff reviewed the application for the modified GE-2000 package design to verify that the package design meets the external radiation limit requirements of 10 CFR Part 71 for NCT and HAC. Staff performed its shielding review using the guidance in Chapter 5, “Shielding Evaluation” of NUREG-1609 “Standard Review Plan for Transportation Packages for Radioactive Material.” This portion of the Safety Evaluation Report (SER) documents the staff’s review pertaining to the adequacy of the shielding design of the package.

5.1 Description of Shielding Design

5.1.1 Design Features

The applicant constructed the Model No. 2000 cask from two concentric 1-inch thick SS cylindrical shells joined at the bottom to a 6-inch steel plate and filled the annulus between the two shells with 4-inches of lead. The applicant designed the cask to be approximately 71.0-inches tall with an outer diameter of 38.5-inches as well as a cask cavity 26.5-inches in diameter and 54-inches deep. The cask lid used 5.38-inches of lead in addition to 1.74-inches of SS above and 1.5-inches of SS below the lead shielding. The applicant also incorporated an internal shielding component, the HPI, which is required for all contents. The HPI body consists of two concentric cylindrical SS shells. The annulus between the two shells is filled with depleted uranium. The applicant developed a material basket, which is described in Section 1.2.2.2 of the application, to be used as shoring. The applicant stated that this component is required when shipping Co-60 rods, but that it is an optional component for shipping irradiated hardware and byproducts. In Section 1.2.4 of the application, the applicant also discussed the use of rod segment holders which may be used for shoring within the material basket. However, the applicant took no credit for the rod segment holders in the shielding evaluation. Therefore, staff determined that the rod segment holders are not important to safety.

Staff reviewed the figures, certificate drawings, and discussion describing the shielding features. The applicant included the shielding features, materials, and dimensions with tolerances; therefore, staff finds that the package is described in sufficient detail to support an in-depth evaluation.

5.1.2 Summary Table of Maximum Radiation Levels

The applicant presented a summary table of the maximum calculated external dose rates for NCT and HAC in SAR Tables 5.1-2 and 5.1-3 respectively. The applicant showed the dose rates for the two requested contents at the locations prescribed by the regulations. For NCT, this included dose rates at the package surfaces, as well as 2 meters from the package side, and the truck cab (representing the normally occupied space). For HAC, the applicant showed the highest dose rate 1 meter from the side, top and bottom of the package surface. Staff reviewed the tables and confirmed that the calculated dose rate levels meet the regulatory dose rate limits in 10 CFR Part 71.47 for exclusive use shipments and the dose rate limits for HAC specified in 10 CFR Part 71.51(a)(2).

5.2 Radiation Source

5.2.1 Irradiated Hardware and Byproducts

As stated in SAR Section 1.2.2.3, the irradiated hardware and byproduct content for the Model No. 2000 included irradiated hardware components composed of SS, carbon steels, nickel alloys, and zirconium alloys. It also included irradiated byproducts such as control rods or control blades composed of hafnium and boron carbide. The applicant identified that the minimum decay time of these components shall be at least 30 days prior to shipment.

The applicant determined the source term for this content type based on the individual nuclides in the content of a given shipment. The applicant listed the nuclides it determined to be significant for this content in SAR Table 5.2-1. The applicant specified that SAR Table 7.5.1-1 must be used when loading irradiated hardware and byproducts to determine if the contents are allowed for shipment. The applicant provided instructions for this table which directed the user to list all of the nuclides to be loaded, the activity of each nuclide, the thermal power of each nuclide and the contribution to external dose of each nuclide for all of the positions listed in 10 CFR 71.47 and 10 CFR 71.51(a)(2). This included surface dose rates for the top, side and bottom of the package, as well as 2 meter dose rates and 1 meter dose rates under HAC for the top, side and bottom. The applicant specified that the sum of all of the decay heats entered into SAR Table 7.5.1-1 shall not exceed 1500 W, and that the sum of all of the dose rates entered into SAR Table 7.5.1-1 shall not exceed 90% of any of the regulatory limits specified in 10 CFR 71.47 and 10 CFR 71.51(a)(2) for any package location. The applicant limited the quantity of the content per package to the lower amount determined by these two calculations.

In SAR Chapter 7, "Operating Procedures," the applicant instructed users to employ SAR Table 5.5-24 to determine the decay heat for each radionuclide present. The applicant took the Q-values within this table are from the SCALE6.1 ORIGEN-S Decay Library origen.rev03.decay.data which, per the SCALE manual, come from the ENDF/B-VII.1 library. Staff considers this data acceptable for determining the decay heat for the Model No. 2000 package because it follows the recommendations of Section 3.3.3 in NUREG/CR-6802. The applicant further stated that the user should use the Q-values from the same library in conjunction with the conversion factors in Equation 5-5 of the SAR for any nuclides that are not listed in SAR Table 5.5-24. Staff finds this method acceptable for calculating decay heat.

To account for the external dose rate contribution of each nuclide, the instructions provided by the applicant for SAR Table 7.5.1-1 instructed the user to employ the SAR Table 5.4-2 (NCT) and Table 5.4-3 (HAC) factors which give the dose rate contribution for each nuclide on a per curie basis. Staff compared the nuclides in these tables and determined that they are the same as those in SAR Table 5.2-1. The applicant evaluated the external dose rate contribution per curie of each of the nuclides listed in these tables for all of the locations and conditions discussed above. For the external dose rate analysis, the applicant also considered the nuclides listed in SAR Table 5.5-2. For the nuclides listed in SAR Table 5.5-2 which do not have corresponding a dose rate contribution per curie in SAR Tables 5.4-2 and 5.4-3, the applicant found these nuclides not to be significant contributors to the external dose rates of the package and can be listed as zero when completing the loading table, SAR Table 7.5.1-1, because the radionuclides to which this rule applies either have no gamma emissions greater than 0.3 MeV or have half-lives less than 3 days. Staff finds this acceptable as gamma energies less than 0.3 MeV would not penetrate the shielding of the package and contents are required to have 30 days decay time which would allow for short lived nuclides to decay to insignificant levels.

The SAR Table 7.5.1-1 instructions provided by the applicant stated that nuclides not listed in Tables 5.5-2 and 5.5-3 of the application may still be shipped if the maximum gamma energy does not exceed 0.3 MeV. In addition, as stated previously, the instructions required that the user must account for the decay heat of any nuclide with a gamma energy that is below 0.3 MeV. The instructions also identified that any nuclide not listed in SAR Tables 5.4-2 and 5.4-3 with a gamma energy that exceeds 0.3 MeV is not allowed for shipment.

The applicant allowed radionuclides that only decay via alpha or beta emissions to be loaded into the package because alpha and beta radiation would not escape the package shielding. However, the applicant required users to account for the decay heat due to these emissions within SAR Table 7.5.1. The instructions also identified that neutron emitting radionuclides are not permitted for shipment except in trace amounts from surface contamination. The applicant clarified in the instructions that any nuclide in an amount less than 1 Ci does not need to be considered in SAR Table 7.5.1. Staff finds that the neglected radiation emissions from this quantity would not significantly contribute to external dose rates because of the conservative assumptions within the evaluation such as the 10% margin to the regulatory limits and neglecting self-shielding of the source material.

The applicant modeled each nuclide in SAR Tables 5.4-2 and 5.4-3 using the gamma spectrum shown in SAR Tables 5.5-3 through 5.5-20. The applicant took these data from the ORIGEN-S data library origen.rev04.mpdkxgam.data. The SCALE manual stated that this data is from the ENDF/B-VII.1 library. Because this library follows the recommendations from Section 3.3.3 of NUREG/CR-6802; therefore, staff finds it acceptable for use in determining gamma emissions for the Model No. 2000. The applicant stated that it considered daughter products from Cs-137 and Zr-95. Staff finds this acceptable because the daughter products of these radionuclides can significantly contribute to the source term whereas the daughter products from the other nuclides in the lists would not significantly contribute to the external package dose rates.

The applicant stated that, although nuclides which do not emit significant gammas were excluded from the table, they are still included in the decay heat evaluation. The applicant stated that other radionuclides which do not emit significant gammas may be present in the irradiated hardware and byproducts content were excluded from the table. Staff finds this approach acceptable because neglecting radionuclides that do not emit significant gamma radiation is unlikely to affect the external dose rates of the package.

5.2.2 Co-60 Isotope Rods

The applicant specified in SAR Section 1.2.2.3 that Co-60 isotope rods must be shipped in the Model No. 2000 in the upright position using the HPI material basket. The applicant specified that Co-60 rods shall be in the form of either pellets or cylindrical solid rods encapsulated in either normal or special form demonstrated to meet NCT. The applicant restricted both the activity of individual rods and the loading instructions such that the activity in any axial 1-inch increment in the HPI cavity is limited to a maximum of 17,000 Ci in order to evenly distribute the radiation source along the length of the HPI cavity and not concentrate the radiation source in a single location.

The applicant stated that dose rate contributions from the Co-60 isotope rods are primarily gamma due to the decay of Co-60 and that contributions from radionuclides in crud that have built up on the rods while the reactor was operating is negligible. Because staff found cases where crud is a significant contributor to external dose rate, staff does not necessarily agree that crud is negligible; however, Step 9 of the loading procedure in SAR Section 7.5.2, required this content to be accounted for within the combined content loading instructions in SAR Section 7.5.3. The applicant provided the Co-60 gamma spectrum in SAR Table 5.2-2. The applicant used the Co-60 energy spectrum from the ORIGEN-S data library origen.rev04.mpdkxgam.data. The SCALE manual stated that this data is from ENDF/B-VII.1 library. Staff finds the data acceptable for use in determining gamma emissions for the Model No. 2000 per the recommendations from Section 3.3.3 of NUREG/CR-6802.

The applicant based the maximum amount of Co-60 allowed for transport on 1500 W. The applicant used the watt to curie conversion from the ORIGEN-S decay library origen.rev03.decay.data to calculate the amount of Co-60 allowed for transport. The applicant provided the generic Watt/curie conversion factors used in SAR Section 5.5.3. Using this method, the applicant calculated the equivalent activity for 1500 W of Co-60 to be 97,250 Ci. As previously stated, staff finds use of this data library acceptable for this purpose based on the research results published in NUREG/CR-6802.

5.2.3 Combined Contents

The applicant also requested authorization to transport irradiated hardware and byproducts as well as Co-60 isotope rods in the same shipment using the Model No. 2000 package. The applicant provided the loading instructions for a combined shipment in SAR Section 7.5.3. This section instructed the user to complete the Tables from SAR Sections 7.5.1 and 7.5.2 and clarified that the package content limit is restricted such that neither the 1500 W total decay heat limit nor the regulatory dose rate limits in 10 CFR 71.47 or 10 CFR 71.51(a)(2) are exceeded. Staff finds this procedure adequate for limiting the combined contents of Co-60 isotope rods, irradiated hardware and byproducts because it provides a reasonable assurance that neither the dose rates nor the decay heat will exceed their respective limits.

5.3 Shielding Model

5.3.1 Source and Shielding Configuration

Staff confirmed that the applicant used dimensions in their shielding model consistent with those in the Model No. 2000 cask drawings. The applicant used nominal cask dimensions to model the Model No. 2000 cask body which is a non-conservative assumption. Although the applicant should account for the possibility of reduced shielding due to manufacturing tolerances, staff found it acceptable for this application because of other conservative assumptions within the source calculation such as not taking credit for self-shielding from source material and the ten percent safety margin on dose rates. The applicant included the dimensions and SS shielding material from the impact limiter in the NCT models; however, the applicant neglected the impact limiter entirely in the HAC models. Staff reviewed the information in Chapter 2 of the SAR and found that all damage from the drop and puncture tests is limited to the impact limiter, which covers the entire surface of the package. Staff also found that the applicant did not credit the impact limiter in the HAC analysis. Staff found this appropriate because neglecting the impact limiters in the models for package under HAC produces conservative results.

For HAC, the applicant also appropriately accounted for lead slump at the top of the lead shielding based on the analysis in SAR Section 2.12.2. However, the applicant neither modeled lead slump at the bottom of the lead shielding nor in the radial direction of the lead shielding which would occur if the cask were oriented in a configuration other than vertical after an accident. Considering the limiting dose rate location for the Model No. 2000 is at the side with the source at the bottom, staff found neglecting lead slump at the side or the bottom of the package to be non-conservative. However, for this application, staff found the applicant's HAC model acceptable due to other conservative assumptions such as the point source representation of the radiological source and the large margin to the regulatory limit in the HAC dose rate evaluation.

In addition to the cask body shielding, the applicant loaded the source into the HPI for supplemental shielding. The applicant considered manufacturing tolerances for this component and selected all dimensions to account for possible reduction in shielding due to manufacturing. Staff found this acceptable. In SAR Chapter 2, the applicant showed there is no effect on the HPI under NCT; therefore, the applicant modeled this component in its nominal as-loaded configuration for NCT. Staff found this acceptable. The applicant showed in SAR Chapter 2 that the HPI remained intact during HAC, and that the radiological source remained inside the HPI. On these bases, staff found that the applicant appropriately modeled the HPI for the package under NCT and HAC.

The applicant credited the shoring provided by the HPI material basket under NCT in that they modeled the Co-60 isotope sources in a vertical position. However, the applicant conservatively neglected the shielding material from the HPI material basket or any other shoring components, such as rod segment holders, that will be within the HPI. Since this is conservative, staff found this acceptable. Since the applicant did not perform an analysis demonstrating the integrity of the material basket during HAC, they assumed that it failed under HAC and modeled the radiological source as a point source. Staff found this acceptable because this modeling assumption maximized the radiological source concentration by neglecting the self-shielding and geometric distribution of the radiological source making the resultant dose rate calculations conservative.

5.3.1.1 Irradiated Hardware and Byproducts

The applicant very conservative modeled the irradiated hardware and by product source for both NCT and HAC as a point source. This assumption is applicable for any geometry of radiological source material because it concentrates the source and neglects self-shielding; therefore, staff finds it acceptable.

5.3.1.2 Co-60 Isotope Rods

To calculate bounding dose rates for NCT, the applicant modeled the Co-60 isotope rod source as a single 12-inch line source with a uniform Co-60 distribution along the length of the source. Assuming a uniform Co-60 distribution produced the most concentrated source term for the applicant's model. The applicant used this source term distribution to determine the dose rate per Ci at different locations and provided the results in SAR Table 5.5-22. Using the values in SAR Table 5.5-22, the applicant calculated the Co-60 activity which results in a dose rate of 90% of the regulatory limits and divided this activity by 12 to determine the Co-60 activity per inch limit of 17,000 Ci; therefore, the applicant restricted the curie content of the Co-60 rods to a maximum of 17,000 Ci in any elevation within the HPI cavity (i.e., with multiple rods shipped side by side, the combination of the total activity at any inch of all of the rods cannot exceed 17,000 Ci). Although this total activity exceeds the quantity of the contents that would be allowed by the 1500 W decay heat restriction, the applicant used it to demonstrate that a minimum radiological source length is not required as long as the 17,000 Ci per inch limit is met.

For the package under HAC, the applicant assumed that the radiological source geometry is a point source. Staff found this acceptable for this package because this is a conservative modeling assumption which results in the highest external dose rate.

5.3.1.3 Source Location

For the point and line sources, the applicant performed evaluations with the source in different locations for each surface dose rate location: top, side or bottom. For the line sources the applicant placed the source at the center of the top to evaluate the top dose rate, the bottom side to evaluate the side dose rate, and the center of the bottom to evaluate the bottom dose rate. The dose rate location at the side of the package near the bottom provide to be limiting because the HPI has the least DU shielding at this location.

Under HAC, the applicant performed evaluations that showed locating the point source at the bottom cavity corner produces the highest external dose rate at one meter. This location produced higher dose rates compared to the top of the package cavity adjacent to the streaming path formed due to the lead slump. This location produced the highest dose rates because, as stated in the previous paragraph, of the reduced DU shielding in this area; therefore; staff found this conclusion acceptable.

5.3.2 Dose Rate Location Evaluations

The applicant provided the locations for calculating dose rates under NCT in SAR` Figure 5.3-4. Staff confirmed that the locations used for evaluating dose rates under NCT are consistent with the distances prescribed in 10 CFR 71.47(b) for exclusive use.

The applicant provided the locations for calculating dose rates under HAC in SAR` Figure 5.3-5. Because the applicant took no credit for the presence of the impact limiter, the applicant located all tally locations under HAC relative to the cask body. Staff confirmed that the locations used for evaluating dose rates under HAC are consistent with the distances prescribed in 10 CFR 71.51(a)(2).

The applicant encompassed the entire exterior of the cask with one centimeter thick tally cells. Although the size of the tally bins shown in SAR Figures 5.3-4 and 5.3-5 are relatively small, staff confirmed the size of the tally bins are appropriate by reviewing the MCNP input files of the representative cases. Staff finds that the tally bins used by the applicant are sufficient to determine the maximum dose rate around the package because the tally bins are small enough to prevent the maximum calculated dose rates from being reduced due to averaging over a volume with lower dose rates.

5.3.3 Material Properties

The applicant modeled SS, lead, and depleted uranium with the compositions and densities listed in SAR Section 5.3.2. The applicant modeled the materials for the HPI with densities equal to that of the minimum values specified in the drawings in SAR Section 1.3.1. Staff finds this acceptable. Staff finds material properties used by the applicant acceptable because they are consistent with the acceptance criteria provided in NUREG-1609.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant performed the shielding calculations using MCNP6 which is a general-purpose, continuous-energy, generalized-geometry, time-dependent, coupled neutron/photon/electron Monte Carlo transport code. The applicant used version 1.0 with the photon transport library MCPLIB84 which compiles data from the ENDF/B-VI.8 data library, and the neutron transport library ENDF71x which compiles data from the ENDF/B-VII.1 data library. The applicant also employed variance reduction techniques to help reduce computation time. The applicant stated that they used MCNP in photon only transport mode to calculate the external dose rate for each content type. Given the code's capabilities, its extensive application and use within the nuclear industry (ensuring the code is well-vetted), and its acceptance by the NRC for these types of applications, staff finds the code acceptable for use in the present application.

5.4.2 Input and Output Data

The applicant provided sample input and output files for the MCNP calculations. Staff reviewed a sample input file and found that the material property information and dimensions used in the calculations to be consistent with descriptions and drawings in the application. In reviewing the output file, staff found that the proper convergence was achieved and that the calculated dose rates agreed with those reported in the SAR.

5.4.3 Flux-to-Dose-Rate Conversion

The applicant used the standard flux-to-dose-rate conversion factors that were derived from the ANSI/ANS 6.1.1-1977 standard consistent with the recommendations in NUREG-1609. The applicant showed the factors used for gamma doses in SAR Tables 5.4-1 and 5.4-2 respectively. Staff confirmed that these factors are appropriate and that they were employed correctly in the sample MCNP input files.

5.4.4 External Radiation Levels

The applicant calculated external dose rates for both contents to ensure they meet both the NCT and the HAC requirements in 10 CFR 71.47(b) and 10 CFR 71.51(a)(2) respectively. The applicant stated that the reported values include 2σ to account for the MCNP uncertainty. The applicant calculated σ by multiplying the percent uncertainty associated with the MCNP calculations by the response function in mrem/hr per curie. Staff finds this acceptable because the reported dose rates are below the regulatory limits.

5.4.4.1 Irradiated Hardware and Byproducts

For the irradiated hardware content, the applicant calculated the external dose rate per curie by evaluating the allowed nuclides listed in SAR Table 5.4-3 individually. The most limiting location for this content is the side surface. The provided the results in SAR Tables 5.4-2 and 5.4-3 for NCT and HAC, respectively, for the side, top and bottom surfaces for all regulatory locations specified in 10 CFR 71.47(b) and 10 CFR 71.51(a)(2). The applicant showed in SAR Table 5.4-

4 that most nuclides are limited by the 1500 W thermal limit. For the few nuclides that are limited by the dose rate, the applicant identified the most limiting dose rate location as the side surface.

5.4.4.2 Cobalt-60 Isotope rods

The applicant showed the maximum calculated dose rates for the equivalent of 1500 W Co-60 (i.e., 97,250 Ci) in SAR Table 5.4-8. The most limiting location for this content proved to be the side surface. The results of the applicant's evaluations showed that the package meets the regulatory limits in 10 CFR Part 71.47 and 71.51(a)(2).

5.4.4.3 Combined contents

The applicant requested authorization to ship a combination of contents in the Model No. 2000 (e.g., Co-60 rods with activated cladding material). For a shipment of combined contents, the applicant directed the user in the SAR Section 7.5.3 operating instructions to separately evaluate the dose rate contributions of each item loaded as discussed in Section 5.2.3 of this SER. The applicant also included in the SAR Section 7.5.3 operating instructions the limitation that the amount of Co-60 cannot exceed 17,000 Ci/inch within any elevation of the HPI cavity. Staff notes that this limitation is specific to Co-60 only; therefore, staff finds this approach non-conservative. However, staff also finds that Co-60 would likely be the most significant radionuclide associated with activated cladding materials (e.g., SS and Inconel); therefore, based on engineering judgment, staff determined that the contribution to the external dose rate by any nuclide other than Co-60 within the activated cladding would not by significant, and that it would be bounded by the conservative assumptions within this evaluation such as neglecting self-shielding material. For these radionuclides, staff determined that the operating procedures in SAR Section 7.5.3 adequately account for the overall contribution to dose rate and decay heat.

5.5 Evaluation Findings

Staff performed its review following the guidance provided in NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material." Based on its review of the statements and representations in the application, staff finds that the shielding design of the package has been adequately described and evaluated and there is a reasonable assurance that the package meets the external radiation requirements of 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

As indicated in their response to staff's request for additional information, the applicant chose not to include fissile material, either in the form of irradiated fuel rods or special nuclear material, as authorized content (ADAMS Accession No.ML17164A287). Therefore, staff removed the "F" from the package identification number to indicate that the package was no longer a Type B fissile package. Recognizing that there might be some limited contamination on either the activated hardware, the byproduct material or the Co-60 rods after irradiation in a reactor or storage in a spent fuel pool, staff conditioned the certificate of compliance to limit the amount of fissile material to a quantity that does not exceed the exempted fissile limits as defined in 10 CFR 71.15 to provide some practical flexibility for use of the package with respect to fissile material contents. Nevertheless, the user shall not consider this as an authorization for shipping fissile materials using this package.

7.0 PACKAGE OPERATIONS

SAR Chapter 7 specified operating procedures for the Model No. 2000 package. The operating procedures included sections on receiving an empty Model No. 2000 package, determining the quantity of contents, loading the package, preparing it for transport or moving it to a storage area, converting it from the storage configuration to the transport configuration, unloading, and shipping it as an empty package. As part of the approval, the users of the Model No. 2000 packaging system are required to perform a number of additional activities while loading or preparing to load the Model No. 2000 package for transport in order to satisfy the design limitations in the areas of structural, thermal containment and shielding.

7.1 Package Loading

SAR Chapter 7 described the operating procedures and requirements for the Model No. 2000 package. SAR Section 7.1 listed the sequence of steps in preparing an empty Model No. 2000 for loading, loading contents, and preparing the loaded package.

The applicant specified in SAR Section 7.1.3.3 "Assembly Verification Pre-Shipment Leakage Testing," that the leakage rate testing is performed on cask lid closure seal and vent port and drain port threaded pipe plugs in accordance with a procedure developed by an American Society for Nondestructive Testing (ASNT) Level III examiner. The applicant stated in SAR Section 7.1.4, "Preparation for Transport," that the overpack temperature will be measured and that particular attention would be given to the area around the bolting-ring. The instructions directed the user to install the protective personnel barrier around the package, in compliance with 10 CFR 71.43(g), if any temperature reading exceeded 185°F. The applicant also imposed vacuum drying criteria which exceeded the criteria in ASTM C1553, "Standard Guide for Drying of Spent Nuclear Fuel." Staff determined that performing vacuum drying in this manner precludes the potential for corrosion of component within the HPI.

7.2 Package Unloading

SAR Section 7.2 provided steps for unloading the Model No. 2000. These steps included receiving the package, preparing for unloading contents, unloading each content type, and releasing the empty cask.

7.3 Evaluation Findings

Staff reviewed the operating procedures for the Model No. 2000 package. Staff followed the guidance provided in the "Standard Review Plan for Transportation Packages for Radioactive Material," NUREG-1609 in its review. Based on the statements and representations in the application, staff concludes with reasonable assurance that the operating procedures provide sufficient specificity and that the package operating procedures meet the requirements of 10 CFR Part 71.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM REVIEW

8.1 Evaluation

The applicant liquid penetrant tested both the root and final passes of all welds associated with the package containment boundary. The applicant also hydrostatically tested the package cavity to ensure structural integrity per ASME B&PV Code, Section III, Subsection NB. The test pressure of 45 psia exceeded the 30 psia design pressure by 50% in compliance with 10 CFR 71.85(b). The applicant leak tested the Model No. 2000 package to the leak-tight criteria of $1x10^{-7}$ ref-cm^3/sec during fabrication in accordance with ANSI N14.5 - 1997. The applicant directed users to leak test each Model No. 2000 package containment boundary seal prior to shipment to ensure the package is leaktight (i.e., leakage less than $1x10^{-7}$ ref-cm^3/sec) in accordance with ANSI N14.5 - 1997. The applicant committed to test each Model No. 2000 package containment boundary seal to ensure the package is leaktight (i.e., leakage less than $1x10^{-7}$ ref-cm^3/sec) every twelve months in accordance with ANSI N14.5 - 1997. The applicant also committed to test each Model No. 2000 package after any maintenance affecting containment components to ensure that the containment boundary remains leaktight (i.e., leakage less than $1x10^{-7}$ ref-cm^3/sec) in accordance with ANSI N14.5 - 1997. The applicant required that an ASNT certification Level III examiner develop the fabrication, pre-shipment, periodic, and maintenance leak testing procedures.

The applicant performed a thermal test on the first Model No. 2000 package built to determine if the package thermal performance conformed to the analytical predictions. The applicant conducted the test with 600 W and 2000 W heat sources in a controlled ambient environment to simulate NCT. Staff noted that a thermal test with a 2000 W decay heat will demonstrate the ability of the package to transport a heat load of 1500 W.

In addition, the applicant proposed to modify the pre-shipment leak test instructions as follows:

- to clarify testing organization references,
- to add both notes and steps to the pre-shipment leak test procedure,
- to update the minimum test duration time period,
- to update leak test acceptance criteria, and
- to allow the use of the gas pressure drop method.

Staff reviewed the proposed changes and determined that they will ensure the package is maintained in a manner which will allow the package to satisfy the requirements of 10 CFR Part 71.

8.2 Findings

Based on review of the statements and representations in the application, staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71, and that the maintenance program is adequate to assure packaging performance during its service life.

CONDITIONS

The CoC includes the following condition(s) of approval:

Condition 1(d) was revised to reflect that the package is not classified as a Type B fissile package.

Condition 3(b) was revised to reflect submittal of a consolidated application.

Condition 5(a)(2) was revised to address use of the HPI and the HPI material basket.

Condition 5(a)(3) was revised to add drawings for the HPI and the HPI material basket as well as remove drawings for structures and components associated with contents no longer authorized for transport.

Condition 5(b)(1) was revised to identify the contents authorized for transport.

Condition 5(b)(2) was revised to identify the maximum amount of allowed contents authorized for transport.

Condition 5(c) was deleted.

Old Conditions 6 through 21 were either replaced with new Conditions 6 through 13 or deleted.

New Condition 13 was revised to reflect the new expiration date.

The references section has been updated to include this request.

Minor editorial corrections were made.

CONCLUSIONS

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, staff concludes that the design has been adequately described and evaluated, and the Model No. 2000 package meets the requirements of 10 CFR Part 71.

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