August 23, 2012

Mr. Patrick L. Paquin
General Manager – Engineering
and Licensing
Energy*Solutions* Services, Inc.
Suite 100, Center Point II
100 Center Point Circle
Columbia, SC 29210

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 9168, REVISION NO.19, FOR THE MODEL NO. 8-120B PACKAGE

Dear Mr. Paquin:

As requested by your letter dated June 30, 2011, supplemented November 30, 2011; May 15, July 20, July 26, and August 10, 2012, enclosed is Certificate of Compliance No. 9168, Revision No. 19, for the Model No. 8-120B package. Changes made to the enclosed certificate are indicated by vertical lines in the margin. The staff's Safety Evaluation Report is also enclosed.

The approval constitutes authority to use the package for shipment of radioactive material and for the package to be shipped in accordance with the provisions of 49 CFR 173.471.

If you have any questions regarding this certificate, please contact Pierre Saverot of my staff at (301) 492-3408.

Sincerely,

/RA/

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

Docket No. 71-9168
TAC No. L24549

Enclosures:
1. Certificate of Compliance No. 9168, Rev. No. 19
2. Safety Evaluation Report

cc w/encl 1 & 2: R. Boyle, Department of Transportation
J. Shuler, Department of Energy
Registered Users

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(Closes TAC No. L24549)

G:SFST\Part 71 Casework\71-9168.r19.letter&ser.doc and 71-9168.r19.doc
ADAMS P8 Package No.: ML12236A191 ADAMS P8 Letter No.: ML12236A198

OFC:	SFST	E	SFST	E	SFST		SFST		SFST		SFST
NAME:	P. Saverot		HLindsay		JIreland		BTripathi		MGordon		DTang
DATE:	08/16/2012		08/17/2012				08/17/2012		08/17/2012		08/21/2012
OFC	SFST		SFST		SFST		SFST		SFST		SFST
NAME	MCall		JSmith		MDeBose		MWaters				
DATE	8/21/12		8/21/12		08/20/2012		8/23/12				

SAFETY EVALUATION REPORT
Docket No. 71-9168
Model No. 8-120B
Certificate of Compliance No. 9168
Revision No. 19

SUMMARY

By letter dated June 30, 2011, Energy*Solutions* (ES) submitted an application to the U.S. Nuclear Regulatory Commission for approval of the Model No. 8-120B package as a -96 package. The June 30, 2011, application replaced in its entirety the January 28, 2011, initial application, and incorporated responses to the Request for Supplemental Information letter dated March 22, 2011. On November 30, 2011, ES provided responses to the first request for additional information (RAI) dated September 30, 2011. On May 15, 2012, ES provided responses to the second round of RAIs dated March 28, 2012.

In addition to a -96 certification request, the applicant modified the contents' limits to allow for quantities up to 3,000 times a Type A quantity, and performed a completely new shielding evaluation to address issues that were raised as part of the review of the Model No. 10-160B package (Docket No. 71-9204).

During the review of the application, the applicant found that, under an Hypothetical Accident Condition (HAC) of a puncture test followed by a thermal test, the sheet metal covering the hollow region of the impact limiters may rupture and provide a direct heat path to the secondary lid and the baseplate of the package, thus exposing the seals to unacceptable temperatures and eventually leading to a loss of containment for the package.

Revision 18 of the CoC was granted under the provisions of Title 10 Code of Federal Regulations (10 CFR) 71.41(c). The regulation in 10 CFR 71.41(c) states that the NRC may authorize a package using environmental and test conditions different from those specified in either 10 CFR 71.71, "Normal Conditions of Transport" and 10 CFR 71.73, "Hypothetical Accident Conditions," if the controls proposed by the shipper are demonstrated to be adequate to provide the equivalent level of safety. In order to demonstrate compliance with the requirements of 10 CFR 71.41(a) for this self-identified design issue and to add the thermal shield to all packages prior to each Type B shipment, Energy*Solutions* provided a revision to the consolidated safety analysis report, and updated drawings as supporting information to this amendment request

On July 20, 2012, ES submitted a consolidated revision of the application, Revision 3, incorporating the addition of a thermal shield as a component of the package along with various updates to the shielding evaluation. The July 20, 2012 consolidated application was further supplemented on July 26 and August 10, 2012.

NRC staff reviewed the applicant's request and found that the package meets the requirements of 10 CFR Part 71.

1.0 GENERAL INFORMATION

1.1 Package Description

The packaging is a cylindrical carbon steel, lead shielded, packaging with four tie-down and two removable lifting devices. It is transported in the upright position with cylindrical foam-filled impact limiters, 102 inches outside diameter (OD), installed at each end of the packaging. The overall height of the package with the impact limiters attached is 132¼ inches. The maximum gross weight of the package is approximately 74,000 pounds (lbs), as follows:

Packaging Body	42,220 lbs
Lid	7,080 lbs
Payload	14,430 lbs
Impact Limiters	4,860 lbs (each)
Thermal Shield	250 lbs

The cavity of the packaging is a right circular cylinder with an internal diameter of 61 13/16 inches and a height of 74 7/8 inches. The package body consists of two shells, both fabricated of ASTM A516, Grade 70 steel. The annular space between the 1½ inch thick external shell and the ¾ inch thick internal shell is filled with 3.35 inch thick lead. The lead shielding is subject to a gamma scan inspection to ensure lead integrity.

The primary lid is attached to the packaging body with twenty equally spaced 2-inch diameter bolts. A supplemental 14 gauge stainless steel sheet is welded to the inside surface of the primary lid. The centered secondary lid is attached to the primary lid with twelve equally spaced 2-inch diameter bolts. A thermal shield, consisting of two polished stainless-steel plates separated by a thin air gap, is attached to the secondary lid lifting lugs with hitch-pins. A 12-gauge stainless steel liner is welded to the cavity of the package and the lid surface to protect all accessible areas from contamination.

The containment boundary consists of the inner shell, the outer baseplate, the bolting ring, the inner O-ring for each lid, and the lids. Test ports for leak testing of the package are located between the twin O-ring seals for both the primary and secondary lids.

There are three configurations of the packaging: Configuration 1 includes a drain port, sealed with the insertion and welding of a rod in the drain port; Configuration 2 does not have a drain port; Configuration 3 does not have a drain port and the packaging's base plate is fabricated differently than for Configurations 1 and 2.

1.2 Licensing Drawings

The staff reviewed Energy*Solutions* Drawing Nos. C-110-E-0007, sheets 1-6, Revision No. 18, which covers all three potential configurations of the package, and Energy*Solutions* Drawing No. DWG-CSK-12CV01-EG-0001-01, Revision 3, for the new thermal shield.

The staff determined that the submitted drawings were generally adequate but requested the addition of several notes on the drawings:

(i) The containment boundary welds cited in Note 30, Subnote A and Subnote B, on sheet 2 of licensing drawing C-110-E-0007, which use progressive magnetic particle examination in lieu of radiography, shall limit the weld metal deposit per pass to the lesser of either 3/8-inch or the critical flaw size as determined by analysis using Section XI of the ASME Code, and

(ii) Components 1, 2, and 3 on drawing DWG-CSK-12CV01-EG-0001-01 shall be made of ASTM A-240 Type 304 or ASTM A-312 TP304 stainless steel with a classification of A.

The applicant inserted the appropriate notations, as requested by staff, on the licensing drawings.

1.3 Contents

Contents include byproduct, source, or special nuclear material in the form of dewatered resins, solids, including powdered or dispersible solids, or solidified material, contained within secondary containers, or radioactive material in the form of activated metals or metal oxides in solid form contained within secondary containers. The secondary containers are not credited with any containment function.

Contents may contain gamma sources, neutron sources and beta sources, i.e, gamma-emitting, neutron-emitting and beta-emitting materials, and are limited to 3,000 times a Type A quantity with further limits as determined in Attachment 1 to Chapter 7 of the application. Gamma-emitting contents are limited to materials with gamma energies up to 3.5 MeV; such a restriction also applies to the peak, or maximum, beta energies for beta sources. Additionally, specific limits are proposed for Co-60 and Cs-137. Powdered or dispersible solid radioactive materials are to have a minimum 60 gram mass or maximum specific activity of $50A_2$/gram.

Contents have a maximum decay heat of 200 watts, and may include fissile materials within limits prescribed by 10 CFR 71.15. However, materials that produce more than $1x10^5$ neutrons/second in the total contents, other than those fissile materials allowed in 10 CFR 71.15, are not authorized. This limit includes materials and combinations of materials that produce neutrons through spontaneous fission, (α,n) reactions, and (γ,n) reactions.

Explosives, corrosives, and non-radioactive pyrophorics are also prohibited. Pyrophoric radionuclides may be present only in residual amounts below 1 weight per cent. Materials that may auto-ignite or change phase at temperatures below 350°F, not including water, shall not be included in the contents. In addition, powdered radioactive materials shall not include radioactive forms of combustible metal hydrides or combustible element metals, i.e., magnesium, titanium, sodium, potassium, lithium, zirconium, hafnium, calcium, zinc, plutonium, uranium, and thorium, or combustible non-metals, e.g., phosphorus.

The staff found that the proposed contents description was very generic in nature. Staff required a source term definition to cover all possible contents that could be transported and address the types of radiation that are (or may be) significant contributors to the package dose rates. The staff's findings regarding the source limits and the shielding evaluation are described in Chapter 5 of the SER.

The maximum weight of contents is 14,430 lbs including shoring and secondary containers.

1.4 Evaluation for the -96 designation

The applicant requested an amendment to Certificate of Compliance No. 9168 to revise the package identification number from USA/9168/B(U)-85 to USA/9168/B(U)-96, as specified in 10 CFR 71.19(e). The staff evaluated the applicant's request, and summarized the impact of the 19 issues proposed in the rulemaking process that resulted in the revised rule, published on January 26, 2004 (69 FR 3698), as described below:

- Issue 1, Changing Part 71 to the International Systems of Units (SI) Only. This proposal was not adopted in the final rule, and therefore no changes were needed in the package application or the Certificate of Compliance to conform to the new rule.

- Issue 2, Radionuclide Exemption Values. The final rule adopted radionuclide activity concentration values and consignment activity limits in TS-R-1 for the exemption from regulatory requirements for the shipment of certain radioactive low-level materials. In addition, the final rule adopted an exemption from regulatory requirements for certain natural material and ores containing naturally occurring radionuclides. The applicant identified no changes to the Model No. 8-120B package as a result of this revision. The staff agrees, based on the design purpose of the Model No. 8-120B package and the allowed contents specified in the certificate. Thus, no changes were needed to conform to the new rule.

- Issue 3, Revision of A_1 and A_2. The final rule adopted changes in the A_1 and A_2 values from TS-R-1, with the exception of two radionuclides. The A_1 and A_2 values were modified in TS-R-1 based on refined modeling of possible doses from radionuclides, and the NRC agreed that incorporating the latest in dosimetric modeling would improve transportation regulations. The applicant stated that this change was not applicable to the Model No. 8-120B. Thus, no changes were needed to conform to the new rule.

- Issue 4, Uranium Hexafluoride (UF_6) Package Requirements. The Model No. 8-120B is not authorized for the transport of uranium hexafluoride. Therefore, no changes were needed to conform to the new rule.

- Issue 5, Criticality Safety Index (CSI). The final rule adopted the new term Criticality Safety Index from TS-R-1. The package can only transport fissile materials within limits prescribed by 10 CFR 71.15, and materials producing more than 1×10^5 neutrons/second in the total contents as described above, other than fissile materials allowed in 10 CFR 71.15, are not authorized. Thus, this section is not applicable and no changes were needed.

- Issue 6, Type C Packages and Low Dispersible Material. This proposal was not adopted for the final rule. Thus, no changes were needed.

- Issue 7, Deep Immersion Test. The final rule adopted an extension of the previous version of 10 CFR 71.61 from packages for irradiated fuel to any Type B package containing activity greater than 10^5 A_2. The contents for the Model No. 8-120B are limited to a 3,000 Type A quantity. Thus, no changes were needed to conform to the new rule.

- Issue 8, Grandfathering Previously Approved Packages. The final rule adopted a process for allowing continued use, for specific periods of time, of previously approved package designs without demonstrating compliance to the final rule. The applicant has submitted, in accordance with 10 CFR 71.19(e), an application demonstrating compliance with the final rule. Thus, grandfathering the design of the Model No. 8-120B package is not necessary.

- Issue 9, Changes to Various Definitions. The final rule adopted several revised and new definitions. These changes were adopted to provide clarity to Part 71. Thus, no changes were needed to conform to the new rule.

- Issue 10, Crush Test for Fissile Material Packages. The revised 10 CFR 71.73 expanded the applicability of the crush test to fissile material packages. The crush test is required for packages with a mass not greater than 500 kilograms (1100 pounds). Since the Model No. 8-120B package has a mass greater than this, and is not a fissile package, the crush test is not applicable. Therefore no changes were needed to conform to the new rule.

- Issue 11, Fissile Material Package Design for Transport by Aircraft. The final rule adopted a new section, Section 71.55(f), which addresses design requirements for packages transporting fissile material by air. The Model No. 8-120B is not a fissile package and is conditioned to be transported only by road.

- Issue 12, Special Package Authorization. The final rule adopted provisions for special package authorization that will apply only in limited circumstances and only to one-time shipments of large components. This provision is not applicable to the Model No. 8-120B package. Thus, no changes were needed to conform to the new rule.

- Issue 13, Expansion of Part 71 Quality Assurance (QA) Requirements to Certificate Holders. Energy*Solutions* Services, Inc., is the holder of Certificate of Compliance No. 9168, and has a NRC approved quality assurance program. No changes are needed to conform to the new rule.

- Issue 14, Adoption of the American Society of Mechanical Engineers (ASME) code. This proposal was not adopted in the final rule. Thus, no changes were needed to conform to the new rule.

- Issue 15, Change Authority for Dual-Purpose Package Certificate Holders. This proposal was not adopted for the final rule. Thus, no changes were needed to conform to the new rule.

- Issue 16, Fissile Material Exemptions and General License Provisions. The final rule adopted various revisions to the fissile material exemptions and the general license provisions in Part 71 to facilitate effective and efficient regulation of the transport of small quantities of fissile material. The Model No. 8-120B package can only transport fissile materials within limits prescribed by 10 CFR 71.15. Therefore, no changes were needed to conform to the new rule.

- Issue 17, Double Containment of Plutonium. The final rule removed the requirement that packages with plutonium in excess of 0.74 TBq (20 Ci) have a second, separate inner container. The application does not include double containment of plutonium. Thus, no changes were needed to conform to the new rule.

- Issue 18, Contamination Limits as Applied to Spent Fuel and High Level Waste Packages. This proposal was not adopted for the final rule. Thus, no changes were needed to conform to the new rule.

- Issue 19, Modification of Events Reporting Requirements. The final rule adopted modified reporting requirements. While the final rule is applicable to the package, no changes were needed to conform to the new rule.

The staff concluded that the design has been adequately described and meets the requirements of the revised regulations in 10 CFR Part 71.

1.5 Findings

The staff concludes that the information presented in this section of the application provides an adequate basis for the evaluation of the Model No. 8-120B package against 10 CFR Part 71 requirements for each technical discipline.

2.0 STRUCTURAL EVALUATION

The staff reviewed the application to verify that the changes made to the package design, as part of this amendment request, meet the structural requirements of 10 CFR Part 71 under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The staff also reviewed the application to determine whether the package fulfills the acceptance criteria of NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material.”

The package is described in Section 1.2 of the “Safety Analysis Report for Model 8-120B Shipping Packaging,” Consolidated Revision 3, dated July 2012, as supplemented. The maximum gross weight of the package is 74,000 lbs. including a maximum payload weight of 14,430 lbs. The impact limiters are 102 inches in outside diameter and extend 22 inches beyond each end of the package, with a 50.0 inch diameter void at each end. Each impact limiter has an external shell, fabricated from ductile low carbon steel, which allows it to withstand large plastic deformations without fracturing. The volume inside the shell is filled with a crushable shock and thermal insulating polyurethane foam. The top and bottom impact limiters are connected together by eight one-inch diameter ratchet binders, allowing for an easy removal of the impact limiters during loading and unloading operations.

2.1 Structural Design

2.1.1 Design Criteria

The structural design criteria, developed by the applicant to assure that the package has adequate structural strength to meet NCT and HAC requirements, are designated as those that affect the containment boundary and other package structures which contribute to the overall structural performance of the package.

Examination of the package’s containment components is based on ASME B&PV Code, Section III, Subsection ND-5000 and that of the non-containment components is based on ASME B&PV Code, Section III, Subsection ND-5000 or NF-5000. Chapter 8 of the application provides additional information on the examination and acceptance criteria for the packaging. The allowable stresses in the bolting for NCT are similar to those for the non-bolting components. For HAC conditions, the allowable stresses are established based on the requirements of ASME B & PV Code, Section III, Appendix F, Article F-1335. Staff finds these criteria acceptable for this application.

The acceptance criteria for the containment boundary, shielding components, and the impact limiters are as follows:

(i) The body of the package and the lid are fabricated of ASTM A516, Grade 70 steel. The containment boundary meets the stress intensity limits of Subsection NB of the ASME Code, Section I, Division I. The containment boundary meets the sealing performance requirements under a free drop event, and also satisfies the ASME code limits for Section III, level A and D stress intensity limits for the respective drop heights. Under a puncture drop, the containment boundary must not be breached, shall remain leak tight, and level D stress intensity limits must be satisfied away from the point of impact. A pair of solid elastomeric O-rings seals the lid-to-cask body and lid-to-lid joints. The containment boundary materials must not be susceptible to brittle fracture.

(ii) The shielding should not separate from the package or suffer extensive damage. Brittle fracture damage resulting in “through-thickness” cracks, thereby causing a loss of the shielding function, is not allowed.

(iii) Impact limiters must (a) perform impact limiting functions such that applicable ASME Section III, Subsection ND stress limits are satisfied for the applicable service condition, (b) remain permanently attached to the package, (c) have adequate crush characteristics to prevent bottoming out of the package body, (d) limit decelerations under the 9 m drop, and (e) have joints with gaskets in the containment boundary that remain fully functional.

Table 2-1 of the application summarizes NCT and HAC loadings and their combination with various initial conditions, used for the design assessment of the package. Table 2-1 has been developed from the guidance of Regulatory Guide (RG) 7.8. Staff reviewed the stress allowable listed in Table 2-2, and the stress components definition presented in Table 2-3, and concurs with the applicant’s approach. The containment boundary is evaluated based on the ASME code requirements and is consistent with Regulatory Guide 7.6.

2.1.2 Weights and Centers of Gravity

The center of gravity of the package is located at approximately the same location as the geometric center of the package.

2.1.3 Identification of Codes and Standards for Package Design

The welding of the containment boundary conforms to Section III, Division 1, Subsection ND of the ASME Code, with exceptions to the code listed in Note 30 on sheet 2 of licensing drawing C-110-E-0007. These exceptions are acceptable to the staff as discussed in Section 8.1.2, "Weld Examinations," of this SER.

Non-containment boundary welds conform to Section III, Division 1, Subsection NF of the ASME Code. The use of these codes corresponds to the guidance in NUREG/CR-3854, "Fabrication

Criteria for Shipping Containers," which the staff finds acceptable. All metallic materials meet ASTM specifications.

The elastomeric seals conform to Energy*Solutions*' procurement document, ES-C-038, "Seal Specification for the 8-120B Cask." This document cites ASTM D2240, "Standard Test Method for Rubber Property; Durometer Hardness," ASTM D2137, "Standard Test Methods for Rubber Property – Brittleness Point of Flexible Polymers and Coated Fabrics," ASTM E1069 and "Standard Test Method for Testing Polymeric Seal Materials for Geothermal or High Temperature Service, or both, Under Sealing Stress," for qualification tests of the containment seal. The ES-C-038 Specification also cites the Parker O-ring Handbook (Parker Hannifin Corporation), a commonly used textbook in the O-ring industry for dimensional and gas permeability characteristics of the seal.

ASTM D2240 is a widely accepted industry test to ensure appropriate mechanical hardness (a requirement for good sealing characteristics) of elastomeric materials. The ASTM D2137 test ensures that the seal material will maintain sufficient ductility under low-temperature conditions to meet the regulatory requirements under 10 CFR 71.71(b), 71.71(c)(2) and 71.73(b). The staff has reviewed ASTM E1069-85 in combination with the required testing temperatures in ES-C-037 and finds that the required 1,000 hour and 70 hour tests are sufficient to ensure with reasonable assurance that the seals will function under NCT and HAC.

The applicant chose to use ASTM E1069-85, in contrast to setting a specific maximum compression set for the seal material after testing. The staff finds a physical test using an actually sealing fixture to be more realistic than the generic requirement of compression set by other tests, e.g., ASTM D395-03. In addition, ES-C-038 limits the seal material to a maximum helium permeability of 100×10^{-8} $cm^3 \cdot cm/cm^2$.sec.bar to prevent operational errors during helium leak testing of the package. Because of the gamma radionuclides being shipped, fluoropolymers are excluded from use as seal materials. The seal material has a limited lifetime of 1-year before replacement.

The impact limiters are filled with closed-cell rigid polyurethane foam, which has a long history as an impact limiting material. Controls on the foam are described in ES-M-175, "Specification for Rigid Polyurethane Foam for Impact Limiters for 8-120B Casks," which defines the required mechanical properties, flammability, density, and acceptance tests for the foam. Flammability resistance is determined using ASTM F-501-93. The staff has reviewed ASTM F-501-93 in combination with the acceptance criteria in ES-M-175 and finds the test acceptable to verify that the polyurethane foam will char but not ignite under test conditions. The mechanical properties of the foam material shall be tested in accordance with TM-9704, "Test Method for Quality Assurance of Crash Resistant Polyurethane Foam," General Plastics Manufacturing Co., Tacoma, WA, September, 1998 (which is in substantial accordance with ASTM D1621, "Standard Test Method for Compressive Properties Of Rigid Cellular Plastics") to verify that foam sample properties are within 10% of the limits of the stress-strain diagrams given in Appendix A to the application. Anisotropy is considered for control of the foam properties.

Density tests of foam samples will be conducted in accordance with TM-9704 to ensure that the density is between 24 – 26 lbs/ft^3 (384 – 416 kg/m^3). In addition, note 32 on sheet 2 of drawing C-110-E-0007 requires the average calculated density of the foam in the impact limiter to be between 24 – 26 lbs/ft^3 (384 – 416 kg/m^3). The staff has reviewed the controls placed on the procurement of the foam and determined that they ensure that the foam properties will match those used in the structural evaluation.

The staff finds that the safety categories of each of the components in the package conform with the guidance in NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Important to Safety," and is therefore acceptable.

2.2 Mechanical Properties of Materials

2.2.1 Material Properties and Specifications

The inner and outer shell of the packaging is made of ASTM A516, Grade 70 steel with thicknesses of 3/4 inches and 1½ inches, respectively. The cask lid is made of two sections of ASTM A516, Grade 70 steel plate. The bottom plate is also made of one ASTM A516, Grade 70 plate. Each plate is 3¼ inches thick. The three-inch thick bolting ring plate is constructed of ASTM A516 Grade 70 steel. Seal rings are made of ASTM A240 Type 304L austenitic stainless steel. The thermal shield attachment is made of ASTM A240 Type 304 austenitic stainless steel plates joined by ASTM A312 Type 304 sectioned pipes. Containment bolting material is made of ASTM A354 Grade BD steel.

The staff has confirmed that the material properties listed in the application match those listed in the applicable ASTM specifications and found them acceptable. The staff notes that the minimum ASTM elongation strain at rupture for ASTM A312 Type 304 is 35% while the finite element analysis of the sectioned piping predicts a 40% strain, in the plastic regime following a puncture test. The FEA strain is reported in terms of true stress and strain, while the ASTM specification requires a minimum engineering strain. As such, the minimum elongation engineering strain of the ASTM A312 Type 304 will be sufficient to prevent rupture of the sectioned pipes during a puncture test.

A 3.35-inch thick shield of cast ASTM B-29 lead between the inner and outer steel shells provides gamma shielding from the package contents. The staff reviewed the ASTM B-29 standard and confirmed its adequacy as a shielding material, as the standard requires a minimum purity of 99.90% lead. Elastomeric seals and impact limiting foam will meet the specifications listed in Energy*Solutions*' procurement documents, ES-C-038 and ES-M-175, respectively.

2.2.2 Chemical Galvanic and Other Reactions

The packaging is fabricated of carbon steel, stainless steel, lead and elastomeric materials. The lead shielding material, which could form a galvanic couple with the ferrous materials, is completely encapsulated and not directly exposed to the atmosphere. Given the expected contents, materials used to construct the packaging, configuration and conditions of transport, the staff finds that there is no safety consideration arising from chemical or galvanic reactions.

Although not intended to act as a corrosion barrier, the thickness of the steel and restrictions on the package contents prevent a reagent from corroding through the metallic portion of the containment under NCT. Therefore, the staff finds that chemical and galvanic reactions will not impact safe transportation of the Model No. 8-120B package.

2.2.3 Effects of Radiation on Materials

The metallic components of the packaging will receive a maximum radiation dose that is orders of magnitude lower than what is required to cause radiation damage. The maximum dose to the seal material is 4×10^5 rad/yr, which is an order of magnitude lower than what is required to cause noticeable damage to most elastomers. Fluoropolymers, which have a threshold dose of 1×10^4 rad/yr, are not permitted for use in this package. The staff finds that the materials used in the packaging, will not be affected by radiation from the package contents.

2.3 Fabrication

Welding of the containment will be done in accordance with ASME Code Section III, Subsection ND. Exceptions are discussed in Section 8.1.2, "Welding Examinations," of this SER. Welding of non-containment components will be done in accordance with ASME Code Section III, Subsection ND or NF. The staff finds that these codes of construction are acceptable and follow the guidance presented in NUREG/CR-3854.

The ASTM B-29 lead radiation shield will be poured into place. The integrity of the shielding material will be verified by means of a gamma scan or gamma probe. The remedy for an unacceptable gamma scan as a result of defects in the lead casting will include actions such as controlled re-heating of the cask body to melt the lead in order to remove any voids or streaming paths. This process may be used as long as the average metal temperatures are kept below 425^{o}C (800^{o}F).

The shell materials that make the annulus of the package are made of 516 Grade 70 steel. The applicant cited the minimum mechanical properties of 516 Grade 70 steel in the application, which assume a normalized state. Therefore, any additional heating of the steel below the austenitizing temperature of about 900^{o}C (1650^{o}F) will not be expected to lower the mechanical properties of the 516 Grade 70 steel below these minimum values.

2.4 General Standards for All Packages

2.4.1 Minimum Package Size

The smallest overall dimension exceeds the specified requirement of 4 inches; therefore, the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper-Proof Feature

The package incorporates a tamper resistant seal that is installed between the package body and each of the two impact limiters after the package has been closed. Breach of the seal would indicate that the package has been tampered with by unauthorized persons. Thus, the requirements of 10 CFR 71.43(b) are satisfied.

2.4.3 Positive Closure

The package uses 20 bolts to fasten the primary lid to the package body and 12 bolts to attach the secondary lid to the primary lid. Additionally, the vent port is closed with a threaded attachment. These closure components are encompassed within the two impact limiters when the package is prepared for shipment and thus cannot be opened unintentionally. The package was adequately analyzed for maximum internal and external differential pressures as well as for expected external and internal pressures during NCT and HAC. Thus, the requirements of 10 CFR 71.43(c) are satisfied.

2.5 Lifting and Tie-Down Standards for all Packages

2.5.1 Lifting Devices

10 CFR 71.45(a) requires a minimum safety factor of three against yielding for the lifting and tie-down devices that are "structural parts of the package." The package is designed to be lifted with two removable lifting ears attached to the side of the package. The primary and secondary lids have each three lifting lugs.

The applicant evaluated the effects of failure of the lifting devices permanently attached to the package, and determined that such a failure would occur away from the containment boundary such that the containment and shielding functions would not be compromised. Staff reviewed the calculations and justifications presented by the applicant in Sections 2.5.1.1 and 2.5.1.2 of the application. For both the package lifting ears and the lid lifting lugs, a dynamic load factor of 1.3 was used to compute the stresses. Staff found these analyses acceptable based on available factor of safety coupled with a conservative loading, and concludes that the requirements of 10 CFR 71.45(a)(1) for lifting devices are met.

2.5.2 Tie-Down Devices

The package is equipped with four tie-down arms to allow rigging components to be connected to the ends of the tie-down arms. Four shear blocks prevent movement of the base of the package.

Loadings in response to the regulatory requirements of 10 CFR 71.45(b), namely 10g longitudinal, 5g transverse and 2g vertical were evaluated by the applicant. Staff reviewed the analysis presented in Section 2.5.2 of the application and found the results acceptable based on the applicant's ANSYS analysis described in Energy*Solutions* Document ST-635 Revision 0.

This analysis showed that the maximum stresses, developed in the tie-down arm, are much higher than those in the package outer shell and, as such, the functional requirements of the package will not be impaired under any excessive postulated loading.

Thus, the staff concludes that the requirements of 10 CFR 71.45(b)(1), as well as those of 10 CFR 71.45(b)(3) are met.

2.6 Normal Conditions of Transport (10 CFR 71.71)

2.6.1 Heat

Staff reviewed the thermal evaluation for the NCT heat condition presented in Chapter 3 of the application. The thermal finite element model, described in Section 3.3, computed the nodal temperature of the package body.

The maximum temperatures in various components of the package are summarized as follows:

Fire Shield = 160.6°F
Outer Shell = 161.3°F

Inner Shell	= 161.5°F
Lead	= 161.4°F
Seal	= 161.7°F
Lid/Baseplate	= 162.6°F

A Maximum Normal Operating Pressure (MNOP) of 35.0 psig is used for the evaluation of the hot and cold environment load conditions. The differential thermal expansion (DTE) of various components of the package is included in the stress calculation of the package. Staff's review of the applicant's analysis indicated that adequate gaps exist between the components but that there is no thermal stresses due to potential material binding. During the review of this section of the application, staff noted that all the components of the package experienced stress well below their allowable values. Of all components, a minimum factor of safety of 1.22 occurs in the bolting ring.

The staff reviewed the calculations presented in the supporting documents and, based on the available factor of safety, determined that the structural performance of the package, under NCT heat conditions, satisfies the requirements of 10 CFR 71.71(c)(1).

2.6.2 Cold

The package must be able to withstand an ambient temperature of -40°C (-40°F) and -29°C (-20°F) in still air and in the shade. The structural finite element model (FEM) used for the analyses of the package under various loading conditions includes the temperature dependent material properties of the package components. The lead shrinkage, due to the differential thermal expansion of the lead and package shells, is also included in the stress calculation of the package. The stresses in the package under the cold environment loading conditions are compared with their allowable values in Table 2-6 of the application. Of all components, a minimum factor of safety of 3.94 occurs in the inner shell.

Staff reviewed the calculations performed in Energy*Solutions* Document ST-626 and the conclusions made by the applicant, and determined that the structural behavior of the package under cold conditions will satisfy the allowable stresses for the materials and components of construction. Thus, the requirements of 10 CFR 71.71(c)(2) are satisfied.

2.6.3 Reduced External Pressure

The MNOP of the package is 35.0 psig (14.7 psi atmospheric pressure). With the external pressure reduced to 3.5 psi, the inside pressure of the package will be 46.2 psi (conservatively rounded up at 50.0 psi in the analysis shown in Energy*Solutions* Document ST- 626). Staff noted that, from the comparison with the allowable values presented in Table 2-8 of the application, all the components of the package experience stress well below their allowable values. A minimum factor of safety of 2.43 occurs in the bolting ring. As such, the staff agrees that the requirements of 10 CFR 71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

The package has been evaluated for an increased external pressure of 20 psi. The MNOP of the package is 35 psig (14.7 psi atmospheric pressure). The package internal pressure was conservatively assumed to be 0 psi, and the external pressure was increased to 25 psi. The load combination for the increased external pressure is listed in Table 2-1 of the application.

The stresses in the package, under the increased external pressure loading conditions, are calculated in Energy*Solutions* Document ST-626 and compared with their allowable values in Table 2-9 of the application. Of all components, a minimum factor of safety of 4.10 occurs in the inner shell. Based on the above results, the staff agrees that the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration

10 CFR 71.71(c)(5) requires that "vibration normally incident to transport" be evaluated. Because of the thickness of the materials used for the Model No. 8-120B package, the package will be unaffected by vibrations normally incident to transport, such as over the road vibrations. Thus, the requirements of 10 CFR 71.71(c)(5) are met.

2.6.6 Water Spray

The containment capabilities of the packaging are not compromised by water spray, because all external surfaces are composed of stainless steel, and the closure seal is impervious to water. Thus, the requirements of 10 CFR 71.71(c)(6) are met.

2.6.7 Free Drop

The structural evaluation of a 1-foot free drop was evaluated in Section 2.6.7 of the application. It was noted that the distribution of reactions and inertia loads used in the FEM analyses were identical to those described for the HAC loading, except that they were linearly proportioned to the ratio of corresponding impact limiter reactions. The results obtained from the detailed FEM analysis of the cask are presented in Tables 2-11 through 2-16 of the application.

Staff reviewed the information presented by the applicant in the tables mentioned above, the corresponding analyses, their validation, and the sensitivity analyses presented in documents referenced as ST-551, ST-596, ST-618, ST-625 and ST-627. Staff concludes that, based on the analytical methodology, approach used, and the subsequent results, the requirements of 10 CFR 71.71(c)(7) are satisfied.

2.6.8 Corner Drop

The corner drop test does not apply since the package is not a fiberboard, wood, or fissile material package. Thus, the requirements of 10 CFR71.71(c)(8) do not apply.

2.6.9 Compression

The compression drop test does not apply since the gross weight of the package is 74,000 lbs (33,637 kg) and exceeds 11000 lbs (5000 kg), in accordance with 10 CFR 71.71(c)(9).

2.6.10 Penetration

The package was evaluated for the impact of the hemispherical end of a vertical steel cylinder of 1¼ inches diameter and 13 lb mass, dropped from a height of 40 inches on to the exposed surface of the package. The penetration depth of the rod was calculated from a Ballistic Research Laboratories formula. The thicknesses of the package's outer shell, lid, outer base plate, and the impact limiter shell are all greater than 0.0147 inches required for penetration. Staff also noted that no credit for the lead shielding and the inner shell was taken in the penetration evaluation. Staff found that the applicant has adequately performed this evaluation, and has demonstrated that it meets the intent of 10 CFR 71.71(c)(10).

2.7 Hypothetical Accident Conditions (10 CFR 71.73)

2.7.1 Free Drop

Compliance with HAC requirements has been demonstrated by analyses in lieu of physical tests. The analysis of the package body was accomplished in two stages: 1) LS-DYNA analysis for the package to calculate the rigid body deceleration, and 2) ANSYS quasi-static analysis of the package subject to the rigid-body inertia loads. Proprietary modeling techniques developed by Energy*Solutions*, using an explicit dynamic FEM, LS-DYNA, for the drop analysis of Type B packages were benchmarked with actual drop test data of a package of a size similar to the Model No. 8-120B.

The analysis of the package was performed in the three customary drop orientations, i.e., end drop with the cask axis parallel to the drop direction, side drop with the cask axis perpendicular to the drop direction, and corner drop with the center of gravity of the package directly over the impact point at an angle of 38°.

The loading combinations in hot and cold conditions were performed per Regulatory Guide 7.8, with an ambient temperature of 100°F and a maximum internal decay heat load for hot conditions, and an ambient temperature of -20°F and the minimum internal decay heat load for cold conditions. The values used for the rigid body acceleration from the impact limiter reactions were conservatively set at 160g for end drop, 150g for side drop, and 75g for the corner drop.

Staff concurs with the applicant's analyses which show that, since the package has a length-to-diameter ratio of 1.29 < 1.37 for cylindrical shape, the oblique drop will be less severe than the side drop. Therefore, the stresses in an oblique drop will be less than those experienced during a side drop.

The details of the modeling techniques and the verification and validation with the test results, documented in an Energy*Solutions* proprietary document ST-551, were reviewed by the staff. Staff found that the modeling techniques used by the applicant predicted the acceleration results conservatively and that the time-history plot of the results of the analyses and of the test data were reasonably close to each other to validate the analyses. Staff also reviewed the applicant's calculations in reference documents ST-625, and ST-627, to verify the assumptions, the approach, and concluded that they were adequate.

However, staff noted during the review of document ST-627, that the formulas for the deflection under a concentrated load on a long cylinder were used to calculate the stiffness of each component of the package wall – outer shell, lead-shield, and the inner shell. The equivalent stiffness of the wall was then calculated by summing up the individual stiffness. Since the material properties of steel and lead are considerably different and because the lead shielding is not chemically bonded to the shell surface, staff requested further justifications for this assumption. Those justifications were included in the report, "Calculation of Stiffness of the 8-120B Cask Wall Components under Concentrated Loads," ST-679 Rev. 0. Stiffness of the individual components and of the composite section were calculated and compared with the theoretical values. The interfaces between the outer shell and lead-shielding and between the inner shell and the lead-shielding were constructed from 3-Dimensional contact elements.

These elements prevent penetration but allow sliding of one surface with respect to another surface. An arbitrary concentrated load of 5,000 lbs was applied at the mid-height of the wall components in the model and the resulting deflection under this load was used to calculate the stiffness. The staff reviewed this calculation and agrees with its results for the purpose of this application.

Staff also requested a justification for the lead slump amount of 0.15 inches and for the punctured lead thinning of less than 0.5 inches resulting from the HAC tests. The applicant substantiated the amount of slump and the extent of lead thinning. Staff reviewed the calculation from the applicant, and noted that the applicant measured the relative displacement of the top of the lead-column and the bottom of the bolting ring. The difference of the total displacements of these two nodes is the relative displacement, amounting to 0.14057 inches, rounded off to 0.15 inches as the value of lead slump. Staff also reviewed the analysis presented in Section 7.5 of ST-627, Rev. 1, and verified the validity of the amount of lead thinning of 0.458 inches, rounded off to 0.5 inches. Staff reviewed the pertinent modeling methodologies, calculation packages, results from the dynamic analyses and comparisons with allowable stresses. The analytical modeling and the results reported, in aggregate, are found acceptable. Hence, staff concludes that the applicant has provided reasonable assurance to comply with the requirements of 10 CFR 71.73(c)(1).

2.7.2 Crush

The regulatory requirement for crush is not applicable as the package weight is greater than 1,100 lbs. and its density is greater than 62.4 lb/ft^3. Therefore, the requirements of 10 CFR 71.73(c)(2) are met.

2.7.3 Puncture

The ability of the package to withstand puncture from a 40-inch end drop onto a 6-inch diameter pin was evaluated by the applicant by treating the end of the package as two simply supported plates with a load at the center. In the scenario of the puncture bar piercing through the top hollow portion of the impact limiter sheet-metal cover, it was also postulated that the puncture bar may contact the thermal shield and possibly the secondary lid bolts.

The thermal-shield is attached to the secondary lid lifting lugs by three hitch pins with a ½ inch diameter and made of ASTM A-276 Grade 304 stainless steel. The total weight of the thermal shield plates is 250 lbs. Based on the material strength and pin shear area, an acceptable deceleration is calculated at 212 g. Staff noted that the largest deceleration (160 g) was experienced by the package during the end drop test. Based on this available margin, the staff concludes that the thermal shield will remain attached to the secondary lid of the package during all the postulated free drop scenarios.

The applicant performed a three-dimensional FEM inelastic analysis (shell models) using ANSYS in the report "CNS Type B Casks Structural Evaluation of the Thermal Shields of the 8-120B & 10-160B Casks under Puncture Drop Conditions." The thermal shield's top plate, made of ASTM A240 Type 304 material, was allowed to plastically deform to 40% strain for this grade material, and the strain resulting from the puncture bar test was then compared with this allowable. Two analyses were performed: (i) the puncture bar striking the thermal shield between the center standoff and two of the six outer standoffs, and (ii) the puncture bar striking between two outer standoffs and the edge of the thermal shield. It was shown that, even though the puncture bar would cause minor damage to the shield near the central portion and the shield plates would deform all the way to the lid with only minor damages, the two stainless-steel plates of the thermal shield will remain intact over most of their area, thus providing thermal resistance during the fire test.

The minimum ASTM elongation strain at rupture of the stainless steel is 35%. The ANSYS analysis presented by the applicant calculates a 40% strain and concludes that this is sufficient to demonstrate that no rupture of the thermal shield has taken place. Staff further noted that, for this analysis, a true stress-strain curve of the stainless steel was input with a bilinear isotropic hardening plasticity. The ASTM 35% rupture strain is an engineering strain while the 40% calculated strain is a true strain. The 35% rupture strain when converted to true strain would be approximately 100% strain based on material test data. By making the most conservative assumption that the state of stress is equal to biaxial tension at the location of the 40% strain, the triaxiality factor would be 2.0, and the true rupture strain would be 50%. This is greater than the 40% strain calculated in this analysis. Therefore, staff concludes that the 40% calculated true strain will not produce rupture, and the thermal shield will remain in place to protect the package secondary lid for the subsequent thermal test. Also, the secondary lid bolts will remain covered by the thermal-shield in this scenario.

Additionally, a conservative evaluation of the bolts was performed with the assumption that the thermal-shield does not provide any cover to the bolts. Staff reviewed this new analysis and concludes that the puncture bar will not cause any damage to the bolts as it was shown that the bolt shear strength was much greater than that of the rod. Overall, staff reviewed the analyses presented by the applicant, and found that the results presented support the conclusions made by the applicant relative to the puncture drop event. Thus, the requirements of 10 CFR 71.73(c)(3) are met.

2.7.4 Buckling

The acceptance criterion for prevention of buckling was based on the criteria detailed in Section 2.7.1.7 of the application. Factors of safety of 2.0 for NCT and 1.34 for HAC were used in the axial buckling stress as well as in the hoop stress evaluations of the package. Staff noted that the thinner inner shell (0.75”) stresses envelope those of the thicker outer shell (1.50”) stresses, and as the maximum inner shell stresses are less than the combined load critical buckling stress intensity, staff concludes that the buckling of the Model No. 8-120B package will not occur.

2.7.5 Thermal

The applicant utilized temperature information from the evaluated fire event to determine the effects on the structural integrity of the package. The stresses in the package under the HAC fire test were compared with their allowable values listed in Table 2-25, and staff noted that all the components of the package experience stresses below their allowable values. A minimum factor of safety of 1.73 occurs in the bolting ring. Staff reviewed the evaluation presented by the applicant and found the conclusions credible; therefore, the requirements of 10 CFR 71.73 (c)(4) are met.

2.7.6 Immersion – Fissile Material

This requirement is not applicable as fissile material is not an authorized content for the package. Therefore, the requirements of 10 CFR 71.73(c)(5) are met.

2.7.7 Immersion – All packages

All the Type-B packages are required to meet the water immersion test specified in 10 CFR 71.73(c)(6), i.e., be subjected to a pressure of 21.7 psig. The package has been analyzed for an increased external pressure of 25 psig in Section 2.6.4 of the application. Therefore, the stresses presented in that section envelope those that will arise due to the immersion test. As such, the requirements of 10 CFR 71.73(c)(6) are met.

2.7.8 Deep Water Immersion Test

This test is not applicable as the package does not contain more than 10^5 A_2. As such, the requirements of 10 CFR 71.61 are met.

2.7.9 Summary of HAC Evaluation

The analyses performed in Section 2.7 of the application show that the package can withstand the HAC tests, specified in 10 CFR 71.73, including the free drop and puncture tests, even though some damage may be experienced:

- During the HAC drop tests, the impact limiter skin may buckle and/or rupture in the vicinity of impact. The rupture may expose a portion of the polyurethane foam that is contained inside the steel skin.

- During the puncture drop test on the sidewall of the package, the fire-shield, which was designed to have a separation from the outer shell, may come in contact with the outer shell due to deformation of the helically wound wire. However, the loss of separation will only be in the close vicinity of the puncture bar end. This will decrease the thermal resistance in that local area and the temperature there may increase slightly from those calculated for the intact package. In the area of the outer shell surface, the temperatures were well within acceptable values.

- During the puncture drop test on the impact limiters, the outer steel skin will deform significantly due to the large compression of the polyurethane foam at the impact point. This may expose a portion of the polyurethane foam that is contained inside the steel skin. However, the seating surface of the impact limiters, which includes the impact limiter attachments, will remain intact as shown in the analysis. Therefore, during the HAC fire test, the impact limiters will provide thermal insulation with a reduced efficiency. The temperature in the critical components of the package will not vary significantly.

- The puncture drop test will not cause a direct impact with any of the port closure plates.

Based on the assessment of the above damages, it was concluded that the package can safely withstand the HAC free drop and puncture tests performed in sequence. The package structural components under these drop tests have been shown to meet the design criteria set forth in Chapter 2 of the application and the staff concludes that the requirements of 10 CFR 71.73 are met.

2.8 Evaluation Findings

Based on the detailed review of Chapter 2.0, "Structural Evaluation," of the application, the review of the analyses and results presented by the applicant, the staff concludes that the applicant has satisfactorily addressed the requirements of 10 CFR Part 71 as applicable.

3.0 THERMAL EVALUATION

3.1 Description of the Thermal Design

The thermal shield lid, added to the design of the package to protect the containment seals during an HAC fire, is made of two polished 1/4 inch and 1/8 inch thick stainless steel plates, covering the entire secondary lid outside surface, i.e., the plate and the bolts. The thermal shield is double-insulated with two air pockets, one between the two thermal shield plates and the other one between the bottom thermal shield plate and the "outside" surface of the secondary lid.

3.1.1 Description of the Modeling of the Thermal Shield

The 200-watt internal heat load is applied as a constant heat flux over the "inside" surface of the secondary lid using a 3-D finite element model (ANSYS) that includes only the secondary lid.

The ambient temperature is set at 1475°F during the 30-minute fire and 100°F during the post-fire cool-down. For radiation heat transfer between the thermal shield and the environment, an emissivity of 0.9 is specified for the 30-minute HAC fire and an emissivity of 0.7347 is used for the post-fire cool-down. Heat is also transferred from ambient to the package by forced convection during the fire transient and from the package to ambient by natural convection during the post-fire cool-down.

3.1.2 Conservative Assumptions in the Model Analysis

The major assumptions used in the applicant's 3-D model are listed below:

- The radiation heat transfer between the primary lid and the secondary lid is neglected to reduce the heat loss from the secondary lid to the primary lid.
- There are no thermal resistances at both ends of the standoff pipes on the thermal shield. The assumed full contact will thus transfer more heat to the secondary lid during the HAC fire.
- The two circular plates of the secondary lid are assumed to be either totally connected or totally disconnected. The larger of the two seal temperatures is selected as the seal's temperature during the fire.
- A larger radiation emissivity of 0.3 is used in the thermal analysis, instead of 0.15 between the two polished thermal shield plates, and 0.074 between the bottom thermal shield plate and the secondary lid during the 30-minute HAC fire. The use of an emissivity of 0.3 will increase the heat input into the secondary lid and the seals.

3.2 Material Properties and Component Specifications

The thermal properties of the structural materials listed in the application were reviewed by the staff against the listed thermal properties in Section II, Part D, of the ASME Code and found to be acceptable. The emissivity of the inner containment shell was set at a conservative value for the thermal analysis, which the staff finds acceptable. During HAC, the maximum temperatures of the packaging components listed in Table 3-2 of the application were below the temperatures expected to cause melting or failure, except for the secondary seal. Under HAC, there is a nominal difference between the maximum operating temperature of the seal and the HAC temperature of the secondary seal. HAC calculations are conservative due to the modeling assumptions; thus, the secondary lid seal will provide containment.

It should be noted that the temperatures in Table 3-2 assumes the complete loss of the thermal shield. If the thermal shield was intact during a hypothetical fire, the secondary lid should remain intact. The staff verified that the ASTM B-29 lead used for shielding has a melting temperature equivalent to elemental lead, 327^{o}C (622^{o}F).

The thermal properties of the impact limiting foam are controlled by the composition (polyurethane) and density (24 – 26 lbs/ft^3). The staff finds that ES-M-175 (which references ASTM F-501-93, "Aerospace Materials Response to Flame, With Vertical Test Specimen (For Aerospace Vehicles Standard Conditions)," is an appropriate industry test for determining the response of the foam material to elevated temperatures. The documentation provided, in response to the first request for additional information (RAI 3-3), both demonstrates that the ends of the package are completely insulated (negligible temperature change of the containment surface) from an HAC fire and provides justification that the thermal performance of the polyurethane foam material is adequate.

3.3 Thermal Evaluation for Normal Conditions of Transport

Two FEM models have been employed to perform the NCT thermal analyses: a three-dimensional (3-D) solid model for the load cases in which the mechanical loading on the package are non-uniform, and a 2-dimensional (2-D) axisymmetric model to obtain the temperature distribution in the package where the bolt loadings have no effect on the results.

The package's geometry is symmetrical about a vertical plane, so one-half model of the package is represented in the 3-D model. The foam in the impact limiter has not been explicitly included in the FEM model. Instead, it has been represented by fully-isolated boundary conditions. For NCT conditions, only the exposed portions of the fire shield and packaging body are used for the heat rejection to the ambient. Figure 3-2 in the application shows the 3-D model used in various thermal load analyses, while Figure 3-3 shows the material property modeling of various components of the package.

The internal heat load has been modeled in two different ways - implicitly (in the 3-D model) and explicitly (in the 2-D model). In the 3-D model, the heat load is applied as a uniform flux over the cavity of the package to result in a conservative package body temperature; however, the cavity temperature predicted is not conservative. To obtain a conservative prediction of the package cavity temperature, the internal contents of the package are explicitly represented in the 2-D model. The package body structural evaluation has been performed with the implicit model results, and the package cavity temperature needed for the calculation of internal pressure has been obtained from the explicit model.

The package structural evaluation has been performed in Section 2 of the application with the temperature results obtained in this section. Table 1 displays the maximum temperatures for various components during NCT.

Table 1: Maximum Temperatures for Various Components during NCT

Component	Maximum Calculated Temperature (°F)	Maximum Allowable Temperature (°F)
Fire Shield	160.6	185
Outer Shell	161.3	Set by Stress Conditions
Inner Shell	161.5	Set by Stress Conditions
Lead	161.4	622
Baseplate	162.3	Set by Stress Conditions
Primary Lid	162.2	Set by Stress Conditions
Secondary Lid	162.6	Set by Stress Conditions
Primary Lid Seals	161.6	180
Secondary Lid Seals	162.2	180
Vent Seal	161.8	180
Impact Limiter	161.9	Set by Stress Conditions
Package Cavity	197.87	Used to calculate MNOP
Waste Contents	197.92	Set by Stress Conditions

The details of the analyses, including the assumptions, modeling details, boundary conditions, and input and output data are included in Energy*Solutions* document TH-027 (Reference 3-8 in the application). Based on this data, the staff found the thermal evaluation for NCT to be acceptable.

3.3.1 Hot and Cold

The 2-D axisymmetric model, with the explicit heat loading, has been analyzed for hot environment conditions. The temperatures resulting from this model have been used to calculate the contents and cavity temperatures. Figure 3-8 in the application shows the temperature distribution in the package and its internal contents.

Under the cold conditions with minimum (zero) heat loading, the body temperature of the package reaches the ambient temperature in steady state; therefore, no thermal analyses for this case are needed. On the other hand, with any amount of heat load, there are temperature gradients in various parts of the package. To capture these two effects, the evaluation of the package was performed for (i) the maximum internal heat load and (ii) the minimum (zero) heat load in order to envelop the conditions of maximum and minimum temperature gradients through the package body.

The thermal analysis shows that there is no reduction in the packaging effectiveness under NCT: the heat transfer capability of the components is not reduced under NCT, nor are there changes in material properties that affect the structural performance, the containment, or the shielding of the package.

It has also been demonstrated that the maximum temperature of the accessible portion of the package is 160.6°F which is less than 185°F, as required by 10 CFR 71.43(g), for an exclusive use shipment. Staff finds the values that are calculated to be acceptable.

3.3.2 Maximum Normal Operating Pressure

The maximum temperature of the package cavity under NCT is 197.87°F (see Table 1). The gas mixture in the cavity is conservatively assumed to be 200°F.

The maximum pressure is the sum of three components: (i) the pressure due to the increased temperature of the gas in the cavity, (ii) the pressure due to water in the package (vapor pressure of water), and (iii) the pressure due to the generation of gases (hydrogen and oxygen) by radiolysis. The MNOP was calculated to be 17.6 psig and was conservatively set at 35.0 psig for use in the package structural analysis under NCT. Staff finds the values that were calculated to be acceptable.

3.3.3 Thermal Stresses

The stresses calculated in the structural analyses under NCT in Reference 3-12 of the application are within the design allowable values established for this package. Staff finds the values that were calculated to be acceptable.

3.4 Thermal Evaluation for Hypothetical Accident Conditions

The impact limiters have been shown to remain attached to the package body during the free drop tests. The effect of these drop tests is a local crushing of the foam, and possible rupture of the impact limiter skin. The puncture drop on the impact limiters will crush the foam and may rupture the skin near the impact location. The rupture of the impact limiter skin after the drop and puncture tests may expose the polyurethane foam material to the fire. However, the polyurethane's fire retardant characteristics will mitigate the effect of the direct exposure to fire due to formation of intumescent char. The intumescent char has the ability to seal large voids, which could be caused by the impact damage. The char also provides a secondary thermal barrier, which breaks down very slowly at about 2,000 to 2,200°F.

The 5-gallon bucket tests performed by General Plastics, where the open face of the bucket is exposed to a direct fire, show the formation of the char that prevents the fire from extending into the underlying foam. These tests also indicate that for a 11¾ inches foam thickness, the effect of a 30-minute fire has a minimal effect on the end opposite to the exposed end. These tests were performed for various density foams, and it was shown that the effectiveness of the foam is enhanced with the increasing foam density. With a 25 lb/ft^3 foam density and a minimum foam thickness of 11 inches in the package, the effect of exposure of a small portion of foam due to rupture during the drop and puncture test will not have a significant effect on the impact limiter performance during the fire. Therefore, the same boundary conditions at the interface between the package and the impact limiter as those under NCT (total thermal insulation) have been used for the HAC fire analyses.

The direct impact of the puncture bar on the sidewall of the cask will remove the air gap provided between the fire-shield and the package body; the fire shield may then come in contact with the package body near the impact location. Analyses have also been performed to evaluate the conditions in which the fire-shield is damaged during the puncture drop test. The fire is assumed to hit the area directly where the puncture bar damages the fire shield. It has been shown in Reference 3-10 of the application that, under these conditions, the package experiences locally high temperatures that are within the acceptable limit for the materials. Therefore, the staff found that the thermal evaluation for HAC is acceptable.

3.4.1 Initial Conditions

There are no changes in this section from the previously approved application.

3.4.2 Fire Conditions

Figure 3-9 of the application shows the boundary conditions used during the fire transient analysis.

3.4.3 Maximum Temperatures and Pressures

The scenario in which the hollow central portion of the impact limiters is breached during the puncture drop test that precedes the fire test has been analyzed in Energy*Solutions* document TH-0002 (Reference 3-11). Figure 3-15 shows the temperature contour plot of the secondary lid with the thermal-shield at the time when the seal temperature attains the maximum value.

The scenario in which the thermal-shield is damaged during the puncture drop test is also addressed in Reference 3-11 of the application, and Figure 3-18 shows the temperature contour plot of the secondary lid with the damaged thermal-shield at 5,400 seconds after the initiation of the fire. The HAC fire analysis is performed with the assumption that the lower hollow portion of the impact limiter has been breached during the puncture drop test that precedes the HAC fire test. Consequently, a portion of the baseplate is directly exposed to the fire, which results in the highest temperature of the cavity. The average package air temperature calculated in Reference 3-11 is 266°F. The nodes that are monitored at these critical components are shown in Figure 3-10 of the application. Figure 3-11 gives the plot of the time-history data at the representative nodes of the package components. Figure 3-12 gives the same data in the components that are not directly exposed to the fire. The maximum temperatures of various components of the package during the entire transient analysis are presented below:

Table 2: Maximum Temperatures for Various Components during HAC

Component	Maximum Calculated Temperature (°F)	Maximum Allowable Temperature (°F)
Fire Shield	1392	N/A
Outer Shell	464.4	800
Inner Shell	295.5	800
Lead	295.8	622
Baseplate	206.3	800
Primary Lid	202.9	800
Secondary Lid	192.6	800
Primary Lid Seals	212.4	235
Secondary Lid Seals	338	340
Vent Seal	206.9	235
Impact Limiter	205.1	500
Cask Cavity	320.5	Temperature used for calculating the cavity pressure
Waste Contents	239.7	Temperature was obtained for reference purpose

The maximum value of the temperature in the cavity is 320.5°F. The maximum pressure during the HAC fire is calculated to be 66.62 psig and was conservatively set at 155 psig. Staff finds that the value for maximum pressure is acceptable.

3.4.4 Maximum Thermal Stresses

The stresses calculated in the structural analyses under HAC in Reference 3-12 of the application are within the design allowable values. Staff finds that the values are acceptable.

3.4.5 Accident Conditions for Fissile Packages for Air Transport

This section is not applicable.

3.5 Evaluation Findings

Staff performed confirmatory analyses by running the applicant's input files in ANSYS. The values obtained are similar to those listed in the application and did not exceed any of the temperature barriers for NCT and HAC.

Based on the review of the ES Document No. CALC-CSK-12CV01-TH-0002, staff confirmed that (1) the thermal-shield design features are adequately described and evaluated, (2) the 2-D thermal model, including only the secondary lid, is described in sufficient detail for verification of the thermal shield effectiveness, and (3) the assumptions, used in the analysis, provide reasonable assurance of conservatism in the calculations and (4) the calculated maximum seal temperature of 338°F is below the allowable maximum limit of 340°F.

Based on review of the statements and representations in the application, the staff concludes that the thermal design has been adequately described and conservatively evaluated, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

4.1 Description of the Containment System

The package containment vessel is defined as the inner shell of the packaging together with the associated lid, O-ring seals, and lid closure bolts. At the base, the cylindrical shells are attached to a circular end plate with full penetration welds. The primary lid is attached to the packaging body with twenty (20) equally spaced ASTM-A354 Grade BD bolts. A secondary lid covers an opening in the primary lid and is attached to the primary lid using twelve (12) equally spaced ASTM-A354 Grade BD bolts. The shells, lids and the bottom plates, which make up the containment barrier, are ASTM A516-70 steel.

The containment boundary material and welds meet the requirement of Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," for Category II packages with impact limiters, which the staff has previously found acceptable. The containment bolts are made of ASTM-A354 Grade BD and will meet impact-energy acceptance criteria of the bolting material in Section III, Division 1, Subsection ND, of the ASME Code at -20°F, in compliance with NUREG/CR-3854. The containment bolts are procured to the highest Safety Classification, "A" in accordance with NUREG/CR-6407, which the staff finds acceptable.

The material properties of the polymeric seals used on the package are controlled by the specification document ES-C-038. The performance of the seal material under different conditions is discussed in other sections of this SER.

In Sections 4.2 and 4.3 of the application, the maximum permitted reference leakage rates (as defined in ANSI N14.5 – 1997) for NCT and HAC conditions are calculated for powdered solids and irradiated hardware waste forms, and the most restrictive of these (i.e., the smallest leakage rate permitted) is taken as the reference leakage rate for the package and as the basis for the acceptance criteria for leak testing.

It is shown that the reference leakage rate (L_R) for the package is 1.54×10^{-6} ref-cm^3/sec. The release limits specified in 10 CFR 71.51(a)(1) are met by limiting the release rate of the package to less than the reference leakage rate. Section 8.1.3 of the application describes leak tests to be performed for each newly fabricated package while Section 8.2.2 describes periodic leak testing. The seals are procured and examined in accordance with Energy*Solutions* Quality Assurance program.

4.2 Evaluation Findings

Based on the review of the statements and representations in the application, the staff concluded that the containment design of the Model No. 8-120B package has been adequately described and evaluated per the change of contents and the package design meets the containment requirements of 10 CFR Part 71.

5.0 SHIELDING

The purpose of the shielding review is to verify that the package design meets the external radiation requirements of 10 CFR Part 71 for NCT and HAC. The applicant modified the contents to allow for quantities up to 3000 times a Type A quantity and performed a new shielding evaluation to address issues that were raised as part of the review of the Model No. 10-160B package (Docket No. 71-9204). Based on the modified shielding evaluation and thermal considerations, the applicant proposed additional conditions regarding the allowable contents quantities. The staff reviewed the application using the guidance in Section 5 of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material."

5.1 Description of Shielding Design

5.1.1 Design Features

The shielding design features a packaging body with a steel base, steel primary and secondary lids and a steel/lead/steel wall, with dimensions specified in licensing drawing C-110-E-0007, Revision 18. The drawing specifies a minimum lead thickness. The only other materials important to, and relied on in the shielding evaluation, are the steel components of the packaging (i.e., the radial shells, base plates and lids). Tolerances for the steel components are set by the ASTM codes specified for these components on the licensing drawings. The two lids have a stepped configuration to reduce streaming from the package cavity. The package also includes a bottom and a top impact limiter.

While the shielding design does not rely on the impact limiter material, it does rely on the presence of the impact limiter to define the package surface for NCT. The impact limiters have a hollow section in the axial middle that is covered by a steel plate. So, the axial end surfaces of the package are at the axial ends of the impact limiters for NCT conditions. Shoring is used, as needed, to maintain the position of the contents within the package. The shielding evaluation credits this shoring for some payload configurations (discussed in Section 5.3 of this SER) for NCT conditions; however, this shoring is not credited in the HAC analyses. The shielding evaluation assumes the package is placed on an 8-foot wide vehicle and is transported as an exclusive use shipment. Based on its identification of the preceding information, the staff finds that the figures, licensing drawing, and discussion describing the shielding features are sufficiently detailed to support an in-depth evaluation.

5.1.2 Maximum Radiation Levels

The applicant provided some sample calculations in the application for a Cobalt-60 (Co-60) point source and a Cesium-137 (Cs-137) point source without credit for shoring. Table 5.1 in the application provides the maximum NCT and HAC dose rates for these two cases. The source strengths for these sources are based upon the applicant's method for determining allowable contents described in Chapter 5 of the application. The staff notes that the dose rates reported for the package side include consideration of the impact limiter side surface and the package body surface between the impact limiters, which the applicant refers to as the package body surface. Staff finds that this is a correct application of the dose rates and the dose rate limits specified in 10 CFR 71.47(b) for exclusive use shipments since there is no enclosure (such as a personnel barrier) around the package or between the impact limiters that prevents access to the package body.

The results show that a Co-60 source and a Cs-137 source with the strengths listed in Column 1 of Table 5.5 (which are for the analyzed configurations for Table 5.1) for these two radionuclides can be transported in the package without exceeding the regulatory dose rate limits in 10 CFR 71.47 for exclusive use shipments and the dose rate limits for HAC specified in 10 CFR 71.51. The NCT dose rate limit for the package surface is the most restrictive limit for these two sources in terms of maximum allowable source strength, or quantity. The source strengths for these radionuclides were selected based on meeting this limit. The applicant has incorporated a 5% margin into the package operations to offset uncertainties in the shielding evaluation method, and thus ensure that the package dose rates do not exceed the regulatory limits cited above.

An application must demonstrate that the package meets the standards described in Subparts E and F of 10 CFR Part 71, per 10 CFR 71.35(a). These standards include the dose rate limits in 10 CFR 71.47 and 71.51. To do this, the applicant proposed a method for determining allowable contents, which will be described later in this chapter of the SER. The method applies to gamma-emitting as well as pure beta-emitting contents. The source strength and source strength density limits in Table 5.5 and Table 1 in Chapter 7, Attachment 1, of the application are the results of that method. The regulatory dose rate limit, of those cited above, that is the most restrictive in terms of allowable contents quantities differs for different contents. Thus, the results in Table 5.1 are examples that demonstrate that package dose rates will meet the regulatory limits for the proposed contents. The allowable source strengths determined by this method may be less than the results from an activity quantity of 3,000 times a Type A quantity. For example, the Co-60 source used for Table 5.1 of the application is only 1.45 Curies (less than 1 Type A quantity). The more restrictive of the content limits must be met for the contents to be acceptable for shipment in the package.

5.2 Radiation Source

Contents proposed for transport include byproduct, source or special nuclear material, in the form of dewatered resins, solids, powdered or dispersible solids, solidified materials, or radioactive materials in the form of activated metals or metal oxides in solid form. All these contents are to be contained within a secondary container(s). As described, the proposed contents may contain gamma sources, neutron sources and beta sources, i.e., gamma-emitting, neutron-emitting and beta-emitting materials.

As described above, the proposed contents limits are 3,000 times a Type A quantity with further limits as determined by the method discussed above. Per the proposed package operations (see Attachment 1 to Chapter 7 of the application), gamma-emitting contents are limited to materials with gamma energies up to 3.5 MeV. This restriction also applies to the peak, or maximum, beta energies for beta sources. Powdered or dispersible solid radioactive materials are to have a minimum 60 gram mass or maximum specific activity of $50A_2$/gram.

The applicant proposed to limit neutron sources in the contents such that fissile materials (as defined in 10 CFR 71.4) are present in quantities less than the limits stated in 10 CFR 71.15 for exempting material from classification as fissile material; other neutron sources are limited such that their total source strength for the total package contents is less than $1x10^5$ neutrons/second. This limit covers production of neutrons from any means, including spontaneous fission, (γ,n) reactions and (α,n) reactions. Based on this limit, the applicant states that the neutron source in the package will not be significant and provides some justification to support this statement; thus, no evaluation of neutron sources was performed.

The staff reviewed the proposed neutron source limits. This review included some conservative hand calculations for determining dose rates at the package surface. The dose rates for these hand calculations were on the order of a few mrem/hr, or about 7% of the NCT surface dose rates limit. The calculations assumed the contents contained fissile material that produced the most significant neutron source along with other neutron sources of $1x10^5$ neutrons/second. The worst case configuration of the source was also assumed (e.g., point source). Based on its review, the staff finds that this limitation of the contents' neutron source is acceptable. Normally, the application should include analyses for neutron sources. However, the staff recognizes the applicant's analysis includes conservatism. This margin includes the quantified conservatisms discussed in Section 5.4.1 of the application and other un-quantified conservatisms, which the staff finds to be sufficient to offset any increase in dose rates due to the proposed allowable neutron sources.

The proposed limits for gamma sources are in terms of specific gamma energies. Additionally, specific limits are proposed for Co-60 and Cs-137. The proposed gamma contents are described in this manner since many nuclides emit gammas at multiple energies and since the contents may contain a mixture of different gamma-emitting nuclides. The proposed limits are set in terms of maximum source strength (i.e., gammas/second) and maximum source strength density (i.e., gammas/second/gram) to address point sources and distributed sources in the contents. These same limits are applied for significant beta sources, which are converted to equivalent gamma sources as described later in this chapter of the SER. A sum of fractions approach is used for contents with multiple gamma energies and/or beta energies. The method considers both point sources and distributed sources. The maximum allowable quantities of gamma-emitters are derived from the limits for gammas at the energies emitted by the radionuclide, which limits are determined in the evaluation method. The method for determining the allowable gamma emissions is based on the most restrictive regulatory dose rate limit. In other words, the maximum allowable gamma emission at a given energy is the smallest emission rate that results in a dose rate that equals a NCT or HAC dose rate limit.

Staff has reviewed the proposed source limits and description. This review included consideration of the proposed contents description. The staff finds that the proposed contents description is very generic in nature and so requires a source term definition that covers all the possible contents that could be transported in the package under that contents description.

Based on its review, the staff finds that the applicant has provided a source term definition that adequately covers the proposed contents, addressing the types of radiation that are or may be significant contributors to package dose rates. These are neutron, gamma and beta (due to bremsstrahlung from significant beta sources) radiation. Specifying the gamma source in terms of specific energies, as described in Chapters 5 and 7 of the application, generically captures any gamma-emitting nuclides and significant beta-emitting nuclides that may be in the contents in terms of source strength and spectra. Therefore, the staff finds the proposed source description to be acceptable. The staff's findings regarding the source limits are described later in this chapter of the SER.

5.3 Shielding Model

5.3.1 Source and Shielding Configuration

The applicant evaluated the package using different models for NCT and HAC. For the NCT model, the steel components of the package are modeled at nominal dimensions and the lead shielding is modeled at the minimum dimension specified in the licensing drawing. Credit is also taken for the presence of the impact limiters though the impact limiter material is neglected. For the top and bottom impact limiters, this includes a steel plate that covers the voided central area of the impact limiters. The package lids are modeled with the stepped feature and gaps between the cavity wall and the primary lid and between the primary and secondary lids to account for any streaming or reduced shielding effectiveness that may occur in these areas. The package is always transported in a vertical orientation; thus dose rate limits on the package are applied for that configuration. For the HAC model the impact limiters are neglected and the lead is assumed to slump 0.15 inches. Additionally, the lead thickness is reduced by 0.5 inches to account for the thinning that occurs in the impact area from the puncture test. This reduced lead thickness is conservatively applied to all the lead shielding. The primary lid also has an additional steel sheet on its base (see the licensing drawing, drawing C-110-E-0007, Rev. 18). This steel is not explicitly used in the NCT and HAC models; so, any shielding due to this steel is neglected. However, it is credited implicitly in that it ensures the position of the package contents remains consistent with the contents positions used in the analyses with respect to the package top flange-to-primary lid gap and the top of the radial lead shielding.

The licensing drawings also indicate that there is a chamfered area in the base of the primary lid. The shielding model includes this chamfer for the HAC point source calculations. Other conditions and other sources do not include the chamfer. The applicant, in its interactions with staff, provided justification for neglecting the chamfer for those other cases, e.g., NCT point sources.

Staff reviewed the applicant's models. The results of the staff's review of the package performance under the NCT and HAC conditions are described in the Structural and Thermal Evaluation sections of this SER. Based upon that review, staff finds that the applicant's models are appropriate for evaluating the package's NCT and HAC shielding performance. Normally, the applicant should model all features relevant to shielding at the minimum thicknesses allowed by the tolerances specified in the licensing drawings. The applicant has done this for the lead shielding but not the steel shielding. The steel components important to shielding, i.e, the lids, base, and the inner and outer radial shells, are modeled at nominal dimensions. The codes listed in the licensing drawing for these components govern the applicable tolerances.

Appropriate tolerances for these components may range up to 0.01 inches. However, as can be seen in the licensing drawing, the package cavity (including the base and the lids) is lined with 12 gauge steel that is neglected in the shielding analysis. This steel also contributes to the package's shielding capability. The thickness of this steel (0.105 inches) is more than sufficient to offset any reduced shielding capability of the package's steel components credited in the shielding evaluation due to negative component tolerances. Thus, the staff finds that use of nominal dimensions for the credited steel package components is acceptable.

The staff also considered the applicant’s treatment of the lid chamfer. Normally, the analyses should consistently address package features that could impact package shielding performance and dose rates. The HAC point source cases do include the chamfer, which did affect some of the maximum allowable source strength limits in Table 5-5 (as well as Table 1 of Chapter 7, Attachment 1) in the application. The staff considered the applicant’s justification for not considering the chamfer in other cases and independently analyzed the potential impacts of adding the chamfer. Considering the potential impacts for HAC for the distributed sources (i.e., the source density limits) and the applicant’s approach to determining source density limits for HAC, the staff finds there is assurance that the approach for distributed sources under HAC bounds the impact on HAC dose rates of any portion of the source filling in the chamfer area.

For some point sources, the limiting dose rate is at a location that would be unaffected by the chamfer. The staff’s evaluation indicated that the difference in the source strength at the limiting location vs. the location(s) impacted by the chamfer bounds the dose rate increase that would result from including the chamfer in the NCT analyses. Thus, for those cases, the staff finds that neglecting the chamfer is acceptable.

For some point sources and some distributed sources under NCT, however, the staff’s evaluation indicated that accounting for the chamfer could impact the source strength and source strength density limits used in the package operations. However, the staff recognizes that the CoC requires that all contents are loaded into a secondary container that is shored within the package cavity, as necessary to prevent movement of the secondary container within the package cavity. The impacts imparted to the package interior from NCT tests are minimal and therefore are expected to have a negligible impact on the secondary container. In addition, with the condition that the secondary container is verified to be correctly sealed by means of a physical check (i.e., not just visual observation) and there is at least two independent verifications of the container’s being correctly sealed, the staff finds that neglecting the lid chamfer for these point source and distributed source cases is acceptable.

Choosing appropriate configurations of the source that bound the possible configurations of the package contents was perhaps one of the most difficult aspects of developing the shielding method. Actual contents may fill the entire package volume, or they may not. They may have mass densities and source strength densities that vary (significantly) throughout the contents volume. There may be the possibility of further concentration or movement of the source due to NCT or HAC conditions. Various source configurations were considered. Thus, an adequate shielding method needs to address these various possible conditions of the contents.

The applicant's method includes several different source configurations to address these scenarios. These configurations include point sources that are centered in the package and point sources located at the package cavity wall away from the impact limiter and point sources located in the top corner of the cavity. The configurations also include uniformly distributed sources of three different volumes (the entire cavity, 55 gallon drum and 2.5 ft^3). The two smaller volumes are centered in the package. All these point and distributed source configurations were used for NCT conditions. For HAC conditions, only the full cavity distributed source and the point source in the top corner of the cavity (nearest the lead slump region) were used. The applicant proposed that these configurations are sufficient to address the possible locations of the contents' radioactive source. Non-uniformity of a distributed source is addressed in the application of the method in the package operations (see Chapter 7 of the application). Conditions regarding which source configuration limits are applied by the package user are also included in the package operations.

Staff reviewed the source configurations used in the applicant's shielding method. The staff's findings are based in part upon the physical configuration and in part upon the material properties assumed in the models. The staff's evaluation of the material properties are discussed in the following section of this SER. The staff's review considered how the results of the method were implemented in the package operations. Based on the considerations of material properties assumed in the method and the implementation of the method results in the package operations, which are described in the appropriate sections of this SER, the staff finds that the analyzed configurations are sufficient to address the different possible contents configurations.

5.3.2 Material Properties

The applicant made minor engineering simplifications for the composition of the packing materials, namely carbon steel and lead, for shielding applications. Based on the low gamma shielding properties of carbon compared to some of the other elements that exist in steels in appreciable amounts, e.g., silicon, the staff finds that the assumption that all steels in the packaging are composed of 99% iron and 1% carbon reasonable. The specification for chemical lead under ASTM B29 requires a minimum lead content 99.90%, which is sufficiently close to 100% lead as estimated in the shielding analysis. The staff finds no safety concerns regarding these estimates of the shield materials' compositions.

The materials in the impact limiters are neglected, although credit is taken in the NCT model for the presence of the impact limiter for purposes of defining the package surface. The material properties of the packaging shielding are given in Table 5.3 of the application. Staff reviewed the materials properties in the table and finds them to be acceptable.

Point sources are modeled as very small cylinders of air. The package cavity for cases with point sources is also modeled as air. Staff finds this to be an acceptable representation of point sources since there is some physical distribution to actual "point" sources and air has a negligible impact on the source (e.g., no self-shielding).

For distributed sources, the applicant assumes the contents are composed of pure zirconium, iron, or aluminum. The contents composition is chosen such that the self-shielding capability is minimized for the contents. The applicant determined the appropriate materials by comparing the mass attenuation coefficients of common materials that could be included in the package contents. The applicant selected the material with the smallest coefficient at each analyzed gamma energy to represent the contents for the analyses. Iron has the smallest coefficient at

0.5 MeV, and aluminum has the smallest coefficient at 3.5 MeV. The applicant found that zirconium has the smallest coefficient for the other energies it analyzed. Thus, the applicant used these materials to represent the contents at the gamma energies analyzed in the shielding method.

Staff reviewed this material selection process. The mass attenuation coefficient is an indicator of a material's gamma-shielding capability. Additionally, the coefficient lends to an easy comparison of the shielding capability of different materials because it removes the materials' densities from consideration. Therefore, the staff finds the process for selecting the material to be acceptable. Staff evaluated the materials considered by the applicant and finds that the applicant's chosen material did have the lowest, or bounding, coefficient for most of the evaluated energies. The staff did find that aluminum may have a smaller coefficient than zirconium at 2.75 MeV; however, the difference is only about 0.6%. This is a small effect. Thus, the staff finds that use of zirconium for the analyses of 2.75 MeV gamma sources is acceptable, but the difference should be considered in evaluating the uncertainties associated with the applicant's shielding method. Some data also indicate that carbon is more bounding for 3.5 MeV gammas than aluminum by up to about 7%. Thus, this impact was also considered by the staff in its evaluation of the method uncertainties and conservatisms described later in this SER chapter.

The staff also considered other materials that may compose the package contents to further confirm that the selected materials are reasonably bounding for the possible package contents. A review of mass attenuation coefficients for other materials indicates that there are other materials with more bounding coefficients than those that were selected by the applicant. Most have coefficients that are lower for only a few of the analyzed energies and do not vary by more than about 8.5% from the coefficient value at the same energy for the applicant's selected material. The variations of most materials are not more than that noted above for carbon, remaining less than about 3.5%. The exception was sodium. However, as the CoC has a condition that restricts the shipment of combustible elements in the package, which includes sodium, it is not expected that sodium could be of sufficient quantities to become a bulk material and warrant addressing its mass attenuation coefficients in the shielding method. Other materials may be ruled out of consideration because of their physical properties (e.g., being a gas at room temperature).

In addition, there are a few other materials which have much smaller coefficients and or are not bounded for a significant number of the analyzed gamma energies. These materials include boron, beryllium, and lithium. Each of these has a coefficient that is more than 10% lower than that used in the applicant's shielding method for one or more of the analyzed gamma energies. The latter two materials have coefficients that are smaller than those used in the shielding method for almost all the analyzed gamma energies. Thus, the staff finds that contents should be limited such that these materials do not constitute a quantity sufficient to be a bulk material for a payload item or portion of that payload item. Given a limitation on the contents with regard to these three materials and the staff's evaluation of the other materials described above, the staff finds that the materials used in the shielding method are acceptable, but the difference in coefficient values described here should be addressed as part of the method uncertainties. The staff included this effect as part of its evaluation of the uncertainties and conservatisms in the shielding method. The staff's acceptance of the applicant's choice of materials is in part based on the margins built into the method.

Another significant part of the method relating to materials is the mass density of the contents' material. This density may vary within a single package. The density may change as a result of

NCT and HAC conditions, depending on how the material density is defined and used in the method. These considerations only apply to distributed sources since material properties are neglected for point sources. The applicant modeled the distributed source with a uniform mass density throughout the source volume. The applicant analyzed the impact of material density on the package dose rates and determined that the optimum density (i.e., the density for which dose rates would be highest) is 9.0 g/cc. Variation in dose rates and the optimum density is addressed by the applicant in its evaluation of uncertainties and conservatisms. The applicant did not consider densities beyond this value as this density should encompass the majority of materials shipped in the package. The package operations state that any payload item with a higher density than 9.0 g/cc is to be treated as a point source.

Staff reviewed the applicant's choice and basis for selecting this density for its analyses. This review included independent confirmatory calculations. The results of these calculations indicate that the applicant's selected density will result in maximum dose rates for the package contents. The staff reviewed how density is used in the package operations to determine the appropriateness of analyzing a uniform contents density. The package operations state that the determination of the payload item's density should not include voids. With this condition, variations in density should not arise as a result of NCT or HAC conditions. With the application of the method results to payload items and even portions of payload items, as appropriate for a particular package loading, staff finds that variations in package contents density is adequately addressed by the shielding method. Based on its review of the method, the results of its calculations, and the stated conditions in the package operations, the staff finds that using a uniform material density of 9.0 g/cc is acceptable for the distributed source analyses.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant performed shielding calculations with MCNP5, Rev. 1.51. MCNP is a three-dimensional Monte Carlo transport code developed and maintained by Los Alamos National Laboratory. The code's capabilities include modeling of and determining dose rates from package design features where radiation streaming may be a concern. This code is used extensively for shielding calculations by industry. Given the codes capabilities and its extensive application in industry (ensuring the code is well-vetted), staff finds the code acceptable for use in the present application.

The applicant proposed a new method for determining the maximum allowable gamma-emitting contents quantities as well as beta-emitting contents quantities. Some aspects of this method have been discussed already in the previous sections of this chapter of this SER. Maximum quantities are for various gamma energies over the range of 0.5 MeV to 3.5 MeV and are based on those quantities that ensure all applicable NCT and HAC dose rate limits are met. The maximum quantities are specified in terms of source strengths (gammas/second or equivalent gammas/second) for point sources and source strength densities (gammas/second-gram or equivalent gammas/second-gram) for distributed sources. More detail regarding the method and the use of its results is provided in Sections 5.4.4 and 5.4.5 of this SER.

5.4.2 Input and Output Data

The applicant provided input and output files for the MCNP calculations used to determine the dose rates for the Co-60 and Cs-137 point sources as well as for the calculations used to develop the method for determining the maximum allowable quantities of gamma-emitting radionuclides described previously. Staff reviewed sample input files and finds that the information regarding material properties and dimensions used in the calculations is consistent with descriptions of the calculations given in the application.

5.4.3 Flux-to-Dose-Rate Conversion

The applicant used conversion factors that were derived from the ANSI/ANS 6.1.1-1977 standard. The applicant calculated the factors from the polynomial fit for gamma radiation given in that standard. As this is the standard that staff finds acceptable for calculation of dose rates, the staff finds the applicant's conversion factors to be acceptable. The conversion factors used in the input files are consistent with those described in the application.

5.4.4 External Radiation Levels

The proposed description of the allowable package contents is, as has already been stated, very broad in its scope. A shielding evaluation that demonstrates that the package with its proposed contents meets the 10 CFR Part 71 dose rate limits is challenging for a package with such a broad range of contents. One potential option is to provide the results of dose rate measurements for a representative set(s) of contents together with adequate justification that the contents for these measurements are sufficiently representative of the proposed contents in the various characteristics that impact the dose rates and shielding performance of the package. Another option is providing an analysis that addresses all the variations in contents characteristics that affect dose rates in an adequately conservative manner. Again, the applicant must justify that the method is adequately conservative.

Staff notes that it is inappropriate to rely purely on pre-shipment measurements for demonstrating package compliance with regulatory limits per the requirements of 10 CFR 71.35, since pre-shipment measurements are not necessarily for a package loaded with contents that are at the maximum parameters allowed by the CoC. Also pre-shipment measurements do not provide any information regarding the dose rates for HAC conditions and whether or not the package dose rates will not exceed the regulatory HAC dose rate limits in 10 CFR 71.51.

The applicant chose a variation of the second option. Instead of selecting the contents and showing that the dose rates do not exceed the regulatory limits, the applicant used the regulatory limits to calculate the maximum quantities of the package contents. The applicant has derived a set of limits for various contents configurations and set restrictions on how the user applies those limits to ensure that the regulatory dose rate limits are not exceeded. This section of the SER will describe the staff's review of that method not already addressed in the preceding sections. Also, since the contents limits are derived from the regulatory dose rate limits, the uncertainties associated with the assumptions and inputs used in the method need to be addressed. The applicant provided some discussion of the uncertainties and the conservatisms in the method, a review of which is described in SER Section 5.4.5. The method is applicable to gamma sources since other limits are specified for neutron sources so that neutron sources do not contribute significantly to package dose rates (see Section 5.2 of this SER).

The package is designed to transport radioactive materials by exclusive use shipment. Thus, the applicant used the 10 CFR 71.47 dose rate limits for exclusive use shipments. There is no enclosure included with the package design, and there are no conditions regarding the vehicle other than a width of 8 feet. So, the dose rate limits for transport in an open, or flat-bad, vehicle are used in the shielding method.

Using the material properties and source configurations described in the preceding SER sections, the applicant determined the source strengths (point sources) and source strength densities (distributed sources) that would meet each NCT and HAC limit for the axial top, axial bottom, and radial side of the package. Since the package is always transported in a vertical position (i.e., the package axis is vertical), the 2 meter NCT dose rate limits were only applied to the package's radial side. These calculations were performed for each of several gamma energies in the range of 0.5 to 3.5 MeV (see Table 5.5 of the SAR) and for the two common source nuclides Co-60 and Cs-137. The results of these calculations were used to create Table 5.5 of the SAR and Table 1 of Attachment 1 to Chapter 7 of the SAR (the package operations).

The quantity limits for distributed sources are in terms of source strength density instead of source strength. This approach is adopted because earlier attempts to define the source in terms of source strength led to conditions where dose rate limits could be exceeded. For instance, a package's contents may meet a specified source strength limit and have the same mass density of material, as used to derive the source strength limit, but be confined to a smaller volume. The source for such a case is more concentrated and results in increased dose rates (vs. those for the source configuration that is the basis of the source strength limit).

Specifying a limit on source strength density ensures that sources do not concentrate without an accompanying increase in the contents' self-shielding to offset the potential dose rate increase due to source concentration. Distributed sources with smaller volumes may have higher allowable source strength densities than larger volume sources; however, their total allowable source strength will be less than the total source strength allowable in larger volume sources. To allow some flexibility in this regard for the package contents, the applicant has proposed limits for three distributed source volumes: the entire package cavity, 55 gallon drum and 2.5 ft^3. Staff finds that defining the contents limits for distributed sources in terms of source strength density instead of source strength is reasonable based on the preceding arguments.

To create the two previously mentioned SAR tables, the applicant compared the source strengths (point sources) and source strength densities (distributed sources) that were calculated to meet each dose rate limit (NCT and HAC) for the locations described above for each of the selected gamma energies and nuclides. The smallest source strength, or source strength density, that resulted in dose rates at a regulatory limit is the most limiting for the contents and is used in the tables as the limit for the contents' source strength, or source strength density, for each gamma energy, or nuclide, for each contents configuration. For the smaller distributed sources, the comparison includes NCT cases with sources having the respective volumes and HAC cases for the full cavity volume. Staff finds this approach for the smaller sources is reasonable since the source strength density for a larger volume source is more limiting than for a smaller volume source. In addition, the use of the full cavity HAC calculated sources accounts for possible shifting of the smaller volume contents' position due to HAC conditions.

Staff finds the overall approach for selecting the smallest source strength, or source strength density, that results in dose rates that equal a regulatory limit to be acceptable since it ensures that all applicable dose rate limits under NCT and HAC conditions will not be exceeded for contents that meet the configuration used in the analyses. Staff findings regarding uncertainties and conservatisms in the method will be described later.

The proposed allowable contents description also allows for significant beta sources in significant quantities to be shipped in the package. Beta sources can indirectly contribute to package dose rates through production of bremsstrahlung. To address this concern, the applicant has proposed that the limits for gamma source strengths and source strength densities also apply to pure beta emitters of sufficient quantities (addressed later) in the package contents. The beta sources are converted into equivalent gamma sources for this purpose. The method for conversion is based on the conversion described in Chapter 5 of Cember's *Introduction to Health Physics* text [1]. The applicant follows the same logic as stated in Cember to determine the equivalent gamma source strength and source strength density and assume that the gamma energy is all at the maximum, or peak, beta energy. This is conservative since beta sources emit betas on a continuous energy spectrum with an average energy that is approximately one-third of the maximum beta energy. So, any bremsstrahlung would also have an energy spectrum ranging below the maximum beta energy.

The applicant proposed that betas emitted from gamma sources can be neglected since the gammas from the source would dominate the dose rates. Also, gamma emitters do not emit significant betas (either in quantity or energy). To support the argument, as well as show conservatism in the overall treatment of beta sources, the applicant performed calculations with MCNP to compare dose rates from equivalent gamma sources to dose rates from beta sources where the code is used to perform the physics of converting the beta into bremsstrahlung. The results indicated significant conservatism. In other words, the dose rates from an equivalent gamma source were significantly larger than the dose rates for the bremsstrahlung from the original beta source.

The staff considered these arguments in its review. The staff also compared the equivalent gamma source strengths for betas emitted by some gamma sources versus the limits for the appropriate gamma energy in Table 5.5 of the SAR. This comparison was done for gamma sources that also emitted betas of relatively high energy. The resulting equivalent gamma source was significantly smaller than the appropriate limits in the table. Considering the conservatism in the conversion method, the result was that the betas from a gamma source would contribute negligibly to the dose rates. This conclusion may not apply for gamma sources that emit betas of sufficient maximum energies and emission rates. At this time, staff is not aware of any gamma source that meets that description. Therefore, the staff finds that neglecting the betas from gamma sources to be acceptable.

5.4.5 Application of Shielding Method Results

The results of the shielding method are captured in Table 5.5 and Table 1 of Attachment 1 to Chapter 7 in the application. Both Chapter 5 and Chapter 7, Attachment 1, describe how the results are to be applied by the package user to determine acceptability of the contents presented for a shipment. The method applies to gamma sources and pure beta sources. The neutron sources must be determined to meet the limits set forth in the CoC.

The shielding method determined the limits for specific gamma energies and two specific nuclides (Co-60 and Cs-137). Gamma sources emit gammas with energies besides those listed in the tables of the application. For a gamma with an energy not listed in these tables, the user must use the limit for the evaluated gamma energy that just exceeds the gamma energy in the contents to be shipped. For contents with gammas of multiple energies, the gammas may be grouped into energy bins such that the maximum energies of the bins are equal to the energies in the tables of the application. The limit for each group is the limit for the maximum energy of the group. Interpolation of limits between gamma energies is not allowed.

Staff finds this approach to be the most straightforward approach and the simplest to apply. The most limiting source strength, or source strength density, is not always the same from one gamma energy to the next of those evaluated and included in the tables of the application. Thus, evaluation of additional gamma energies and inclusion of limits for them in the tables of the application would be necessary to ensure interpolation, if allowed, was only done in energy bands where the basis for the source strength limit, or source strength density limit, was consistent. With only the energies currently listed in these tables, staff finds that prohibiting interpolation of limits between gamma energies is appropriate.

Additionally, interpolation of limits between distributed source sizes is also prohibited. In order to use the limits for a distributed source volume, the contents must meet the volume and dimension specifications and the shoring requirements specified in Attachment 1 to Chapter 7. The staff finds this is acceptable as it is supported by the applicant's shielding analyses.

The package user does not need to consider gammas with energies below 0.3 MeV. Betas with peak energies below 0.3 MeV may also be neglected. The user does not need to determine an equivalent gamma source for package contents containing a total beta source strength from pure beta sources (peak energy ≥ 0.3 MeV) that is less than 2E+12 betas/second. Gammas (and betas) with energies below 0.3 MeV should contribute negligibly to package dose rates given the package's shielding, particularly the radial shielding. The same is true, and even more so, for beta sources with peak energies below 0.3 MeV. Therefore staff finds that neglecting gamma and beta sources with energies below this level is acceptable. The applicant calculated the dose rates from a beta source, using MCNP to perform the physics for converting betas to bremsstrahlung and found that a beta source of 2E+12 betas/second would contribute up to about 1% to the package dose rates, which the applicant addresses as an uncertainty in the method. The staff finds that, because the uncertainty from this proposed threshold is addressed by the applicant and that uncertainty is small, this threshold for consideration of beta sources in the package is acceptable.

An additional limit on the contents is that sources with gamma and/or peak beta energies greater than 3.5 MeV are prohibited. The applicant's analyses only support shipment of contents with gamma and peak beta energies up to this level.

The package operations include the method for conversion of betas to equivalent gammas. The conversion depends upon the material in which the betas interact. Materials with higher atomic numbers (i.e., Z), produce more bremsstrahlung than do those with lower Z. The position of the beta source may be anywhere within the contents, including next to the secondary container, or liner, in which the contents are placed. The applicant has proposed that the user determine the weighted-average Z of the contents (excluding the liner) and the weighted-average Z of the liner and use the larger of the two values to calculate the equivalent gamma source. The staff finds this acceptable because the highest value results in a bounding equivalent gamma source regardless of the position of the beta source within the contents.

To determine the acceptability of the contents presented for loading, the applicant uses both a source strength limit and a source strength density limit. The appropriate limits are selected based on the contents meeting the criteria for using those limits. These criteria are specified in the package operations and were described in previous sections of this SER. For each gamma energy (group) the user determines the source strength and source strength density present in the contents. For source strength density, averaging over the contents is not allowed. The user must use the highest source strength density in any portion of the contents. The user compares the contents source strength density and source strength to the respective limit for each gamma energy (group) and chooses the smallest fraction (i.e., the smallest of the two ratios: contents source strength/source strength limit and contents maximum source strength density/source strength density limit). The sum of these fractions over all gamma energies (energy groups) must be less than 0.95 for the contents to be acceptable to ship.

The user has the option to perform this operation on individual items, or components, in the contents (referred to by the applicant as payload and payload items). In this case, the source strength density for the payload item is the maximum for any portion of that item (averaging over the item is not allowed) and the summation of fractions is over all energies (energy groups) over all payload items. By using the maximum source strength density of the contents or contents items, the staff finds that the method adequately addresses possible conditions of non-uniform distribution of sources within the contents. Further changes in distribution of contents due to NCT and HAC are adequately addressed, as discussed elsewhere in this section and previous sections of this SER.

Staff had several questions regarding the use of the limits as proposed by the applicant. One dealt with treatment of contamination or other loose, powdery or granular radioactive material that was not in some way bound (e.g., physically or chemically) to the bulk material of the contents. It is possible for this material to redistribute under NCT or HAC conditions, maybe settling out on its own. To address this kind of condition, the applicant proposed that these kinds of sources must meet the source strength limits; the source strength density limits cannot be used. Staff also notes that this kind of source cannot be considered a shored source since it has the potential to move within the contents volume. So, the appropriate limit would be the source strength limit for an un-shored, or general, source. The staff finds that, based on its judgment, this approach is acceptable because the un-shored point source limits are the most restrictive limits in terms of total allowable source strength and the mass of this material may be difficult to determine.

Another question focused on un-shored payload items in shored payloads. An example of this scenario is a 55 gallon drum shored in the package that has a piece of activated hardware somewhere within it. If the user evaluates the contents by payload item, analyzing the hardware piece separate from the rest of the contents in the drum, the concern is that the user would also treat this hardware as shored as well. An accurate application of the contents limits per the package operations indicates that the activated hardware cannot be considered shored unless it is shored within the cavity of the 55 gallon drum that is itself shored within the package cavity. The staff finds this application of the limits is acceptable based on how the limits are derived in the shielding analysis.

Somewhat related to the preceding question, the staff considered the appropriateness of using the shored source strength limit as one of the limits for determining acceptability of contents in small containers that are shored in the package cavity. The shored source strength limit is based on a point source that is shored in the package cavity. One thought was that a more appropriate limit would be one that was based on a point source in the part of the smaller volume's cavity that maximized dose rates. This process would be similar to how un-shored and larger volume (more than 55 gallons) sources are treated. The applicant includes examples of how the contents limits are applied in various situations. The limit for which the fraction was lowest always was the limit that staff thought made sense based on the physical characteristics. Staff recognizes that this may not always be the case, but anticipates that it will often be the case. Based on this consideration and expectations for the contents configurations that will be shipped in the package, the staff finds that using the shored source strength limit as is done in the package operations is adequate for this application.

As noted above, the limit for which the fraction is lowest is used to determine the acceptability of the contents. In the examples attached to the package operations chapter in the application, the fraction that was lowest was consistent with staff's view as to the appropriate limit for the contents item based on the item's physical characteristics. This may not always be the case. For gammas of different energies, for example, the limit for which the fraction is lowest may be different for the same item. The size of these items would be relatively small in mass versus the allowable contents mass for which this situation would apply. Such a volume would likely be very small in volume compared to the volume of the cavity, though it could be on par with the smallest of the smaller shored volumes. However, based on expectations for the contents configurations that will be shipped in the package, the staff finds that using the limit for which the fraction is lowest to determine contents acceptability is adequate for this application.

5.4.6 Uncertainties and Conservatisms

Since the method for determining the maximum quantities of radioactive contents is derived from the regulatory dose rate limits, the applicant addressed the uncertainties in the method.

The applicant accounts for statistical uncertainty in the calculation results, the impacts of neglecting bremsstrahlung for total beta source strengths less than 2E+12 betas/second, uncertainty in the determination of the mass density that maximizes dose rates, and some uncertainties in identification of the bounding mass attenuation coefficients for the evaluated energies, particularly the lowest and highest energies. The uncertainty in the MCNP calculations is less than 5%, with the uncertainty for most of the calculations much less than that. The other items identified by the applicant amount to less than 3% uncertainty in, or impact on, the results.

The applicant also described the conservatisms in the method, quantifying some of them to demonstrate that the conservatisms adequately offset the uncertainties. The source strength and source strength density limits in the SAR tables include adjustments to account for the statistical uncertainties in the MCNP results. The applicant identified the use of bounding mass attenuation coefficients, the method for addressing bremsstrahlung (i.e., converting betas to equivalent gammas), and other aspects of the method as conservatisms that more than offset the uncertainties. For the bremsstrahlung, calculations indicated significant conservatism, the applicant noted factors of more than 100. Staff notes that at higher energies this may be somewhat smaller but still significant. The applicant also includes a 5% administrative margin in the package operations for determining the acceptability of package contents.

In its review, the staff also identified additional sources of potential uncertainty. The following is a description of those uncertainty sources.

Because of the restrictions on neutron sources in the contents, the contribution of neutron sources is taken to be negligible and is therefore not analyzed for the package dose rates and accounted for in setting the gamma source limits. Using conservative assumptions, the neutron sources may result in an impact to dose rate limits up to 7% of the dose rate at the package surface.
Additionally, staff's review indicated there may be additional uncertainties associated with the selection of the bounding mass attenuation coefficients. The uncertainties vary with gamma energy and material. Some are eliminated due to conditions in the certificate regarding those materials (see Section 5.3.2 of this SER). Thus, the additional uncertainty from this aspect of the method may be up to about 7%, though generally it is on the order of 3.5%.

The method and the use of the results include conservatisms in addition to those mentioned. A strict numerical comparison of the total maximum uncertainties and total quantified conservatisms indicates that the conservatisms do not entirely offset the uncertainties. However, the maximum uncertainties do not necessarily match up for the same gamma energies. Thus, the total uncertainty at each gamma energy is less. Also, there are a number of un-quantified uncertainties in the shielding method and the use of the results. These include those identified by the applicant as well as restrictions on interpolation of limits between gamma energies and volume sizes for smaller volume, shored contents. The degree of conservatism introduced by each of these items varies with gamma energy, but it is present. In addition, the staff's calculation of uncertainty due to the neutron source contribution to dose rates is determined in a conservative manner.

Based on its review of the uncertainties and conservatisms, accounting for the factors described in this SER section as well as expectations regarding the actual package contents, the staff finds that the conservatisms in the shielding method and the use of its results in the package operations adequately offset the uncertainties in the method.

5.5 Evaluation Findings

Based on its review of the statements and representations in the application and independent confirmatory calculations, the staff finds reasonable assurance that the shielding design has been adequately described and evaluated and that the package meets the external radiation requirements of 10 CFR Part 71.

5.6 Reference

Cember, Herman, *Introduction to Health Physics*, Third Edition, McGraw-Hill, New York, 1996. (See pages 129-131 for estimating bremsstrahlung.)

6.0 CRITICALITY EVALUATION

Not applicable.

7.0 PACKAGE OPERATIONS

Loading of the package requires inspection of the package lifting ear bolts and the bolts securing the cask primary and secondary lid for signs of cracking or damage. Bolts which show signs of distress shall be replaced and the bolt holes will be examined for any signs of significant degradation. If the bolts holes are damaged, a procedure listed in Section 8.2.5.1 for using threaded inserts to repair damaged bolt holes will be used, which the staff has reviewed and found acceptable.

As stated in Section 7.1.8, seal surfaces will be cleaned; both seals and seal surfaces will be inspected prior to loading and damaged seals will be replaced. Visible package external and internal surfaces will be visually inspected for defects, dents, etc. As stated in Section 7.1, the package will not be used as a Type B package until damage is assessed by Energy*Solutions* and, if required, repaired to bring the packaging into conformance with the licensing drawings. The staff finds the materials related loading procedures acceptable.

The package operations include procedures, given in Attachment 1 to Chapter 7 of the application, for determining the allowable contents quantities, with respect to radiation source term, that may be transported for a given shipment. The basis for these procedures is described in the shielding evaluation in the application and in reference 5.7.2 of the application. The procedures address gamma sources and pure beta sources only; limits on neutron sources are specified in CoC Condition 5.(b)(2). The procedures do address both point sources and distributed sources. Staff reviewed these procedures and finds that they are consistent with the basis described in the shielding evaluation and the noted reference. Examples are also included in Attachment 1 to illustrate how the procedures are used. The staff reviewed the examples and finds they are consistent with the procedures.

The staff also reviewed the package operations to ensure that specific operations relevant to shielding are adequate. These include the use of shoring to maintain the contents position within the package, the performance of dose rate surveys to ensure the package meets the regulatory dose rate limits and that these radiation surveys are sufficient to account for non-uniformity of the source distribution, and the use of appropriate limits for preparation of empty packages.

The applicant stated that for any package containing water and/or organic substances which could radiolytically generate combustible gases, a determination of hydrogen generation must be made using the methods in NUREG/CR 6673. The staff finds that such determinations of hydrogen concentrations as shown in Attachment 2 to Chapter 7 of the application are acceptable.

The staff performed a confirmatory analysis of hydrogen generation with LSA material in the Model No. 8-120B package. The bounding analysis was performed using the maximum decay heat (200 watts), the maximum allowable limit of hydrogen in volume (5%), the maximum energy emission and absorption fraction (1.0), and the conservative effective G value in radiolysis (0.6 molecules per 100 eV for LSA material) to minimize the allowable shipping time for hydrogen generation. Calculations were performed with the weight fractions of water, 1% and 2%, respectively, contained/absorbed in the LSA materials. Both calculations show that (i) it would take significantly longer than 100 days to reach the 5% hydrogen generation limit for the LSA material, and (ii) it should not generate hydrogen above the 5% limit, if the package is shipped within the 10-day condition.

Based on these findings, the staff concludes that the operating procedures both meet the requirements of 10 CFR Part 71 and are adequate to assure the package will be operated in a manner consistent with its evaluation for approval

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Weld Examinations

Weld examinations of containment and non-containment components will meet the acceptance criteria in ASME Code Section III, Division 1, Subsection ND and Subsection NF for Class 3 support welds, respectively. The staff finds these codes, which follow the guidance presented in NUREG/CR-3854 acceptable.

Exceptions to the weld examinations are listed in Section 8.2.2.1 of the application and on note 30 of licensing drawing C-110-E-0007. Subnote A and B of note 30 permit the use of progressive magnetic particle inspection in lieu of radiography due to the geometry of the weldment. The staff finds that radiography or ultrasonic examination of these welds is acceptable.

Progressive surface examination is acceptable in situations where volumetric examination of welds is not possible, e.g., lid-to-shell welds on multi-purpose spent fuel canisters under the guidance in ISG-15, "Materials Evaluation," and ISG-18, Rev. 1, "The Design and Testing of Lid Welds on Austenitic Stainless Steel Canisters as the Confinement Boundary for Spent Fuel Storage." Subnotes A and B of note 30 of the licensing drawings limit the amount of material deposited per weld to the lesser of 3/8-inch (the basis is the material deposition limit in ND-2539.4, "Examination of Repair Welds") or the critical flaw size, based on a flaw-size analysis in compliance with Section XI, Division III, of the ASME Code. Subnote C of note 30 permits the combination of ultrasonic examination and magnetic particle examination in lieu of radiography, which is in compliance with ND-5279, "Special Exceptions." Section 8.2.2.2 specifically highlights welding examinations that exceed the requirements for Class 3 components under Subsection NF of the ASME Code, which is acceptable to the staff.

8.2 Component and Material Tests

All metallic materials used in the packaging meet ASTM specifications. The staff finds this consistent with approval of radioactive transportation packages for carrying non-spent fuel contents. The O-ring seals will meet the requirements in Energy*Solutions*' document, ES-C-038. This procurement document for the polymeric seals specifies that the seals will pass the low temperature test of ASTM D2137, Method A at -40°C, ensuring adequate sealing performance at low temperatures, which the staff finds acceptable. The properties of the impact limiting foam are controlled by Energy*Solutions*' procurement specification, ES-M-175.

The weld examinations of the lifting and tiedown lugs shall be performed in accordance with the applicable Subsection of the ASME Code before and after a 150% load test as stated in Section 8.1.2.5 of the application. The staff finds these examinations acceptable before and after loading testing as they exceed the examination requirements stated in NUREG/CR-3854.

Mechanical testing of the containment boundary material and welds will be in accordance with Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)." The staff finds that the Regulatory Guide, although acceptable, does not provide significant conservatisms for Category II packaging with impact limiters. The fracture critical bolting material will meet the cold-temperature acceptance criteria of the bolting material in Section III, Division 1, Subsection ND of the ASME Code, as stated in Engineering note 14 on sheet 2 of licensing drawing C-110-E-0007. This will comply with guidance presented in NUREG/CR-3854, which the staff finds acceptable.

The qualification testing of the bolts comply with the guidance presented in NUREG/CR-3854, which the staff finds acceptable. Low temperatures will not affect austenitic stainless components, which are ductile at cryogenic temperatures.

8.3 Maintenance Program

Visible cask external and internal welds will be visually examined for weld defects on an annual basis. Elastomeric seals will, at a minimum, be replaced on an annual basis, as stated in ES-C-038. An annual replacement of polymeric seals is consistent with the guidance in Section 8.5.2.2 of NUREG 1609.

8.4 Shielding Acceptance Tests

The applicant modified the shielding acceptance tests which are focused on ensuring the adequacy of the package's radial lead shield. Section 8.2 of the application describes the acceptance tests for packages fabricated after April 1, 1999. The shielding acceptance tests in Section 8.1 of the application have been kept as they are in the currently approved revision of the CoC. The staff finds this acceptable because any significant repair of the package that includes repair of the package lead shield is treated as new fabrication, which means that the acceptance tests in Section 8.2 of the application will apply. The shielding acceptance criterion has been changed to be clearly consistent with the specifications of the minimum lead thickness on the licensing drawing. The licensing drawing note regarding acceptance testing has also been changed to rely on an acceptance criterion that is clearly consistent with the specification of the minimum lead thickness on the drawing. Other acceptance tests described in Chapter 8 are sufficient to ensure the shielding performance of the other package components relied on in the application's shielding evaluation.

8.5 Evaluation Findings

The staff has reviewed the acceptance tests and maintenance programs. Based on this review, the staff finds that the acceptance tests for the packaging meet the requirements of 10 CFR 71 and that the maintenance programs are adequate to ensure the packaging performance during its service life.

CONDITIONS

The conditions specified in the Certificate of Compliance have been entirely rewritten to incorporate several changes as indicated below:

Item No. 3.a has been revised to identify Energy*Solutions* Services, Inc., as the certificate holder.

Item No. 3.b has been revised to identify Energy*Solutions*' application dated July 20, 2012, as supplemented.

Condition No. 5(a)(2) has been entirely rewritten for clarity purposes. The thermal shield and other changes in the description of the packaging are also included.

Condition No. 5(a)(3) has been revised to include Energy*Solutions* Drawing No. C-110-E-0007, sheets 1-6, Revision No. 18 for the three configurations of the packaging, and Energy*Solutions* Drawing No. DWG-CSK-12CV01-EG-0001-01, Rev. 3, for the thermal shield.

Condition No. 5(b)(2) has been entirely re-written to clarify the maximum quantities of materials per package, and the determination of their limits in accordance with the results of the new shielding analysis.

Condition No. 7 has been added to verify the correct sealing of the secondary container by two independent physical verifications of the container's closure system.

Condition No. 8 has been rewritten to link shipments of powdered radioactive materials to the leak test requirements of Section 4.8 of Chapter 4 of the application.

Condition No. 10 limits the flammable gas (hydrogen) concentration to less than 5% in volume. Compliance with this concentration limit is determined by the methodology used in NUREG/CR-6673.

Condition No. 11 requires a pre-shipment leak test before each shipment of Type B quantities.

Condition No. 12 authorizes the use of the current packages in accordance with the Addendum of the application, until August 31, 2013, while new lids are fabricated and seals are tested. The addendum is constituted as follows:

> Section 1 has the current (current means the SAR referenced in CoC Rev. 17) package description with the addition of the thermal shield, current contents, current drawing (Rev. 13) and inclusion of the thermal shield drawing; it notes that the Rev. 13 lid will be uniquely marked.
>
> Sections 2 and 3 reference the new structural and thermal Chapters 2 & 3 of the application dated July 2012.
>
> Section 4 is a copy of the current containment chapter with the current leak test provisions.
>
> Sections 5, 6, & 7 references the new Chapters 5, 6, & 7 (including installation of the thermal shield) of the July 2012 application.
>
> Section 8 is a copy of the current Chapter 8.

Condition No. 14 changed the expiration date of the Certificate to August 31, 2017.

CONCLUSION

Based on the statements and representations in the application, as supplemented, and the conditions listed above, the staff concludes that the Model No. 8-120B package design has been adequately described and evaluated and that these changes do not affect the ability of the package to meet the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9168, Revision No. 19,
on August 23, 2012.