SAFETY EVALUATION REPORT
Docket No. 71-9316
Model Nos. AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S Packages
Certificate of Compliance No. 9316
Revision No. 0

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SUMMARY

By application dated June 19, 2009, as supplemented September 14, 2009, September 29, 2010, October 19, 2011, and February 1, 2012, Alpha-Omega Services, Inc. (AOS) requested approval of the Model Nos. AOS-025, AOS-050, and AOS-100 as Type B(U)-96 packages. Revision No. F of the package application, dated February 1, 2012, supersedes in its entirety the application dated June 19, 2009.

The Model No. AOS-100 package design is the design basis for all other models. All package designs consist of a stainless steel outside shell and cavity encasing a shielding cylindrical cavity, made of tungsten alloy or carbon steel, to provide containment for the contents. Additional components include the shielding and lid plugs, the packaging bottom plate, the lid and lid seal, and the impact limiters. Variations in the designs of the various models pertain to shielding materials, the size and number of bolts, the foam density and the size of the models, with the Model Nos. AOS-025 and AOS-050 packages being scaled down to respectively 25 percent and 50 percent of the size of the Model No. AOS-100 package.

The package is designed to ship Type B quantities of solid activated radioactive materials, either as normal form or special form. The width of the package is approximately 18 inches for the Model No. AOS-025A package and 61.08 inches for the Model No. AOS-100A-S. The maximum gross weight of the loaded package ranges from 220 lbs. for the Model No. AOS-025A to 1,500 lbs for the Model No. AOS-50 and up to 12,500 lbs. for the Model No. AOS-100A-S package.

NRC staff reviewed the application using the guidance in NUREG-1609 "Standard Review Plan for Transportation Packages for Radioactive Material." The analyses performed by the applicant demonstrate that the package provides adequate structural, thermal, containment, and shielding protection under normal and accident conditions. Based on the statements and representations in the application, and the conditions listed in the Certificate of Compliance, the staff concludes that the package meets the requirements of 10 CFR Part 71.

References

AOS application “AOS Radioactive Material Transport Packaging System Safety Analysis Report for Model AOS-025, AOS-050, and AOS-100 Transport Packages,” Revision No. F, dated February 1, 2012.

1.0 GENERAL INFORMATION

Alpha-Omega Services, Inc. (AOS, the applicant) submitted an application for five (5) new transportation packages in accordance with 10 CFR Part 71. These packages consist of the Model Nos. AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S. The “A” designation refers to a tungsten shield, and the “B” designation refers to a carbon steel shield. The “S” designation on the AOS-100A-S means that the package is double ended with a lid on each end of the package. The packages have the same geometry, with the Model Nos. AOS-025 and AOS-050 having all dimensions scaled to 25% and 50% (respectively) to the Model No. AOS-100 package.

All packages are Type B(U)-96 packages designed for the transport of radioactive materials including by-products, sources, and special nuclear materials either as normal form or special form.

1.1 Packaging

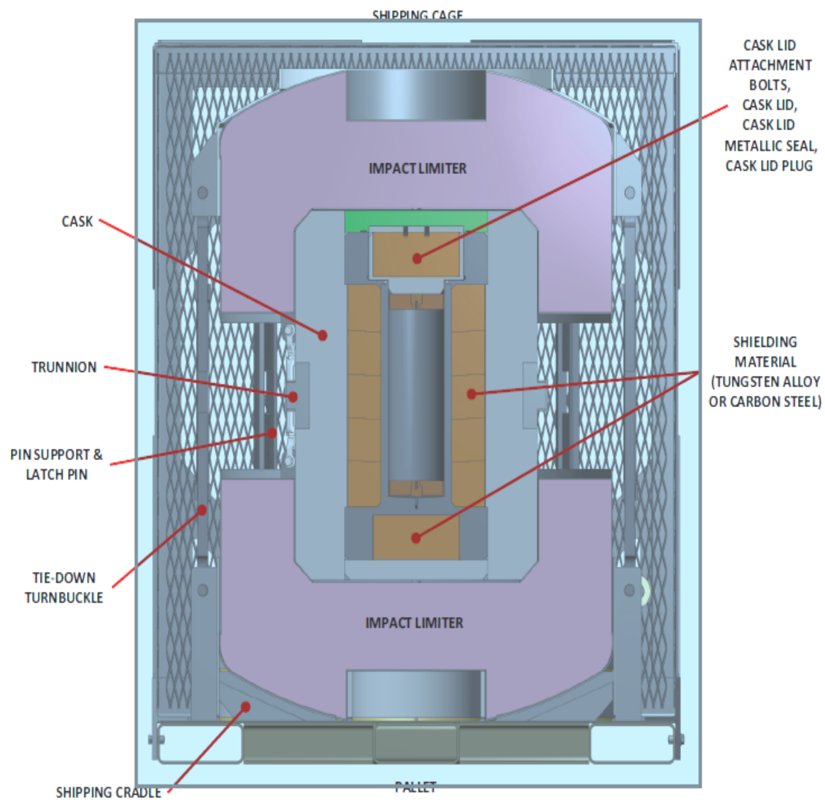
The packaging is made of a 300 series stainless steel cylinder with a welded base-plate and a bolted lid (closure plate). The lid plate incorporates a metallic, double “C” shaped silver jacket, energized by a stainless steel spring, in the lid groove, to ensure the containment function. The containment system consists of the packaging inner shell, the base plate, the top flange, the top closure plate, the top closure metallic seal, the vent port closure system, and the drain port closure system.

The inner shell of the packaging forms an internal cylindrical shielded cavity. The shielding cylinder and plugs, made of tungsten alloy or carbon steel, enhance the package shielding characteristics. Additional packaging components include the nickel alloy lid bolts, the vent and drain port plugs, the O-ring seals and the port plug covers.

The impact limiters consist of a thin-walled stainless steel cylindrical shell, filled with polyurethane foam of varying density depending upon the size of the package, with a dish head at one end and a flat disk at the other end. At the dish-head end, another recess is provided to reduce the area available for impact during a head-on drop event.

Twelve (12) squared ribs are attached to the inner wall of the cylindrical recess section of the flat disk end. Eight (8) of these ribs extend beyond the flat disk plate, and are used as turnbuckle attachment points. The turnbuckles join the impact limiters and partially enclose the packaging (see Figure No.1). For the Model No. AOS-025 package, the impact limiters entirely cover the packaging and the turnbuckles are replaced with “J” hooks.

Figure No. 1: Model No. AOS-100 Package in a Transport Configuration



During transport, the package is attached to either an aluminum transport pallet, for the Model Nos. AOS-025 and AOS-050, or a steel shipping cradle, for the Model No. AOS-100, and surrounded by an aluminum shipping cage bolted to the pallet or the cradle.

The approximate dimensions and weights of the various models are indicated in Table No. 1 below:

Table No. 1

AOS Transport Packaging System Dimensions and Weights

Model	Packaging OD (in.)	Packaging Height (in.)	Cavity OD (in.)	Cavity Height (in.)	Maximum Package Weight (lbs.)
AOS-025A	7	9	1.62	5	220
AOS-050A	14	18	3.25	10	1,500
AOS-100A	28	36	6.50	20	12,500
AOS-100B	28	36	6.50	20	11,000
AOS-100A-S	28	36	6.50	20	12,500

1.2 Contents

The package is used for transporting Type B quantities of activated solid radioactive materials, including metals, that meet normal or special form definitions in 10 CFR 71.4. All dispersible normal form material is encapsulated into a sealed secondary container which is considered to be a “shoring device.” Any material with a melting point less than 1,000°F shall be in special form. Fissile materials and irradiated fissile materials containing fission products are prohibited. No free-standing liquid is authorized.

The maximum decay heat is 10 watts for the Model No. AOS-025A package, 100 watts for the Model No. AOS-050A package, and 400 watts for Model Nos. AOS-100A, AOS-100A-S, and AOS-100B packages.

The maximum weight of contents, including any shoring devices and any additional shielding plates, is 10 lbs for the Model No. AOS-025A package; 60 lbs for the Model No. AOS-050A package; and 500 lbs for the Model Nos. AOS-100A, AOS-100A-S, and AOS-100B packages.

Table 2 below lists the activity limits for each isotope that can be shipped as encapsulated solid material or solid metal meeting normal or special form criteria. The contents are limited for all package models by either the assigned decay heat or the shielding limitations of the design. The Model No. AOS-025 package requires the use of a liner, while the Model No, AOS-050 does not. The Model No. AOS-100 package requires the use of axial shielding plates for large-quantity shipment of ^{60}Co in all its configurations, i.e., either the Model Nos. AOS-100A, AOS-100B, or AOS-100A-S packages.

An optional shoring ensures that the loading arrangement is maintained during transportation. All shoring materials within the package’s cavity must have a melting point greater than 538ºC (1000ºF).

There are no moderating materials or neutron absorbers in the contents, nor any other material that would create a chemical, galvanic, or other reaction leading to the release of combustible gases.

Table No. 2 - Activity Limits (TBq)

Isotope	AOS-025	AOS-050	AOS-100A AOS-100A-S	AOS-100B
Co-60	4.55E-03	7.84E-02	123	0.362
Co-60 (1)	-	-	810	4.14
Cs-137	0.392	11.1	2950	19.5
Hf-181	-	81.4	3370	138
Ir-192	2.68	47.7	2410	85.8
Zr/Nb-95	-	1.06	913	2.36
Ho-166	0.44	6.55	-	-
Yb-169	147	1470	-	-
Shipping Configuration	Use of Liner required	No additional shielding required	(1) Axial shielding plates required	(1) Axial shielding plates required

1.3 Materials

The components for the containment boundary comply with ASME B&PV Code, Division 1, Subsection NB requirements, while Important To Safety Components comply with Division 1, Subsection NF requirements.

Material and manufacturing control processes are carried out using written procedures to ensure that all critical characteristics are met.

Staff reviewed the materials selected for use in the fabrication of components of the package and found that they meet the service requirements of such components. Staff also found that such materials are consistent with NUREG/CR-3854.

1.4 Drawings

The packaging is constructed and assembled in accordance with the following Drawing Nos.:

Model	Assembly	Rev.	Impact Limiter	Rev.	Packaging	Rev.	Liner/Axial Shielding Plates	Rev.
AOS-025A	166D8142	F	105E9722	E	166D8143	E	183C8485	E
AOS-050A	105E9718	F	166D8138	E	166D8137	E	-	-
AOS-100A	105E9711	F	105E9713	E	105E9712 G001	E	183C8491	E
AOS-100B	105E9711	F	105E9713	E	105E9712 G002	E	183C8491	E
AOS-100A-S	105E9711	F	105E9713	E	105E9719	E	183C8491	E

1.5 Evaluation Findings

A general description of the Model Nos. AOS-025, AOS-050, and AOS-100 packages is presented in Section 1 of the package application, with special attention to design and operating characteristics and principal safety considerations. Drawings for structures, systems, and components important to safety are included in the application.

The application identifies the AOS Quality Assurance Program, PR9000, “Quality Assurance Program radioactive Material Packaging,” Revision No. A, and the applicable codes and standards for the design, fabrication, assembly, testing, operation, and maintenance of the package.

The staff concludes that the information presented in this section of the application provides an adequate basis for the evaluation of the Model Nos. AOS-025, AOS-050, and AOS-100 packages against 10 CFR Part 71 requirements for each technical discipline.

2.0 STRUCTURAL REVIEW

The objective of the structural review is to verify that the structural performance of the package meets the requirements of 10 CFR Part 71, including performance under the tests and conditions for both normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

2.1 Structural Design

2.1.1 Description of Structural Design

The Model No. AOS-100A package forms the basis for the design of the other packages approved under this application, i.e., the Models No. AOS-025A, AOS-050A, AOS-100B, and AOS-100A-S, which include variations such as shielding materials, foam density, and bolt sizes, or to accommodate standard size components.

The packaging body is manufactured with stainless steel 300 series while the cavity shielding insert is made of tungsten alloy or carbon steel. The stainless steel thin shell impact limiters, filled with polyurethane foam, attach to one another by eight (8) turnbuckles and are configured in such a manner that, under all potential free-fall scenarios, the collision of the package with the surface (essentially unyielding target) will always occur in the crush material space.

All models use a metallic, double "C" cross-section, seal between the lid and the packaging body cavity. The seal is attached to the lid by four screws positioned in such a way as to prevent the screws from interfering with the deformation of the "C" cross-sections when the lid bolts are being tightened. The seal design provides a means for leak testing between the two "C" cross-sections, through the cask lid's test port feature.

The package, with impact limiters attached, is secured inside a shipping cage. The shipping cage is a five-sided metal structure, with a pallet creating a sixth side, designed to prevent inadvertent access to hot areas on the package and enclosing the package during transportation, to provide a barrier between the public and the package. The pallet is used to tie down the package to the conveyance surface.

The Model No. AOS-100A-S is double-ended and has a lid/lid plug combination at both ends. The Maximum Normal Operating Pressure (MNOP) is 20 psia for the Model No. AOS-025 package, and 21 psia for the Model Nos. AOS-050 and AOS-100 packages.

2.1.2 Design Criteria

The structural design criteria are developed to assure that the AOS package has adequate structural strength to meet NCT and HAC requirements. These criteria are designated as those that affect the containment boundary and those that affect other package structures which contribute to the overall structural performance. The containment boundary is evaluated based on the ASME code requirements for level A and D service and is consistent with Regulatory Guide 7.6 "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels."

2.1.3 Weights and Centers of Gravity

Section 2.1.3 of the application summarizes the varying weights and center of gravity locations for the different models. The maximum weights, including contents and shipping cages, are: 220 lbs for the Model No. AOS-025 package; 1,500 lbs for the Model No. AOS-050 package; 11,000 lbs for the Model No. AOS-100B package, and 12,500 lbs for the Model Nos. AOS-100A and AOS-100A-S packages.

2.1.4 Codes and Standards

The codes and standards utilized for the package design are identified in Section 2.1.4 of the application. Specifically, the containment boundary is designed and fabricated to the ASME Code Section III, Division 1, Subsection NB. Other components important to safety are designed and fabricated to the ASME Code Section III, Division 1, Subsection NF. As these codes and standards are consistent with the recommendations documented in NUREG/CR-3854, the staff finds them to be acceptable.

The codes and standards applicable to the package materials are specified in the packaging drawings and in Section 2.3.1, Table 2-18, of the application. The materials used for the fabrication of the components of the packaging are in general accordance with the applicable rules of ASME Section II, Parts A, B, and C, as applicable. Materials not covered by these codes include (1) the tungsten shielding material, fabricated in accordance with SAE-AMS-7725D Type 2 Class 3, and (2) the impact limiter foam, a specialty material manufactured according to General Plastics' procedures for the FR-3700 Series Foams. Welding procedures and personnel are qualified in accordance with the ASME Code, Section IX.

The staff finds that the codes and standards listed above for the materials, design and fabrication of the packaging are acceptable. The staff found that specifications for the codes, materials, and weld types, are on the appropriate drawings. Thus, 10 CFR 71.31(c) is met.

2.2 Material Properties

The materials and properties of the packaging components are provided in Section Nos. 2.2 and 3.2 of the application. These properties are consistent with the properties in the standards referenced in the licensing drawings. The staff finds that the requirements of 10 CFR 71.119 are met.

2.2.1 Packaging Shell

The outer shell, packaging cavity shell, and port plug are ASME SA-182/ASTM A182 Grade F304 or Grade F316 austenitic stainless steel. The lid, lid plug, cover plate, and bottom plate are made from ASME SA-240/ASTM A240 Type 304 or Type 316 stainless steel. The trunnions are ASME SA-479 Type 304 or Type 316. Alternative materials for the above components, also austenitic steels, are given in Table 2-18 of the application. Because of their corrosion resistance and mechanical properties for the range of temperatures experienced by the package, the staff finds the choice of 300 series stainless steels acceptable for the fabrication of the packaging shell. The lid attachment bolts are ASME SB-637 Grade 07718 nickel alloy. The trunnion screws are ASME SA-193 Grade B6 carbon steel.

There are no coatings or lubricants used in this packaging. No neutron shield is needed. All structural materials are 300 series stainless steel or ASME SB-637 Grade 07718 nickel alloy, with no nil ductility point above -40°C (-40°F); thus, there was no need to consider the fracture toughness of these materials.

The modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, density, ultimate tensile stress, yield stress, and design stress intensity provided in Table 2-9 of the application for the 300 series stainless steels have been checked against the ASME B&PV code Section II, Part D, and found to be correct for the entire range of temperatures presented. Similarly, the conductivity, thermal diffusivity, and specific heat provided in Tables 3-7 and 3-80 of the application for the 300 series stainless steels have been checked against the ASME B&PV code Section II, Part D, and found to be correct for the entire range of temperatures presented.

The modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, density, ultimate tensile stress, yield stress, and design stress intensity provided in Table 2-10 of the application for the nickel alloy lid bolts have been checked against the ASME B&PV code Section II, Part D, and found to be correct for the entire range of temperatures presented.

The mechanical properties provided for the SA-193 Grade B6 trunnion screws have been checked against the ASME B&PV code Section II, Part D and found to be correct.

2.2.2 Gamma Shield

The axial and radial gamma shields that are an integral part of the packaging are either tungsten ATI Densalloy SD180 per SAE-AMS-7725D, Type 2, Class 3, or carbon steel forging per ASME SA-105. The shields are embedded in the packaging's body and lid plug. Model Nos. AOS-025 and AOS-050 packages have the tungsten alloy shielding, while the Model No. AOS-100 package has either the tungsten alloy or the carbon steel shielding. The carbon steel shielding is electroless nickel plated with a minimum thickness of 21 μm in order to reduce the potential for galvanic corrosion.

In addition to the packaging's shielding, the Model No. AOS-025 package requires the use of a liner for all shipments, and the Model No. AOS-100 package requires the use of axial shielding plates for higher quantity shipments of Co-60. All the components of the liner and the axial shielding plates are made of the same tungsten ATI Densalloy SD180 per SAE-AMS-7725D, Type 2, Class 3. All the components of the liner and the shielding plates are electroless nickel plated with a minimum thickness of 21 μm to reduce the potential for galvanic corrosion.

The modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, density, and yield stress provided in Table 2-11 of the application for the tungsten alloy have been found to be correct. Similarly, the conductivity, thermal diffusivity, and specific heat provided in Tables 3-6 and 3-79 of the application for the tungsten heavy alloy have been checked against independent references and found to be correct for the entire range of temperatures presented.

The modulus of elasticity, Poisson's ratio, coefficient of thermal expansion, density, ultimate tensile stress, yield stress, and design stress intensity provided in Table 2-12 for the carbon steel shielding have been checked against the ASME B&PV code Section II, Part D, and found to be correct for the entire range of temperatures presented. Similarly, the conductivity, thermal diffusivity, and specific heat provided in Tables 3-7 and 3-80 of the application for the carbon steel shielding have been checked against the ASME B&PV code Section II, Part D, and found to be correct for the entire range of temperatures presented.

Since neither of these materials has a structural function and the maximum fire temperature is well below their melting points, the staff sees no materials issues with the use of these shielding materials.

2.2.3 Seals

The metallic lid seals are comprised of a double "C" shaped silver jacket energized by a stainless steel spring. Documentation of the environmental testing to demonstrate the seal's performance within the applicable temperature range was provided in Section 3.5.10 of the application. The staff finds the seals acceptable for use over the maximum 1 year duration of transport.

The packaging has three penetrations. The first, located on the package lid, leads to the area between the "C" cross-section seals that is used to test the adequacy of the seal joint. The other two penetrations are the cavity drain and vent ports. These ports are closed by port plugs with three diametrical steps, a central cylindrical hole, and a threaded end at the smaller diameter. The port plug seals and conical seals are made of C10100, C10200, or C11000 copper. Each of these two port plugs connect to the cask cavity shell. An elastomeric Parker

Silicon S1224-70 compound O-ring, attached to the port cover, provides a seal for these penetrations. According to the Parker handbook, the operating range for the silicon O-ring is -54°C to 232°C (-65°F to 450°F). Based on the maximum temperatures predicted for HAC and NCT conditions for all model sizes (224°C per Tables 3-3 and 3-4 of the application), and based on the manufacturer test data provided in Section 2.12.5 of the application (Parker material report), the staff finds that the choice of Parker Silicon S1224-70 compound is acceptable for the port cover O-ring.

2.2.4 Impact Limiters

The impact limiters are made of a thin shell of ASME SA-240 Type 304 or Type 316 stainless steel filled with closed cell polyurethane foam of the General Plastics FR 3700 Series. The foam density is 18 lbs/ft^3, 8 lbs/ft^3, and 11 lbs/ft^3 for the Model Nos. AOS-025, AOS-050, and AOS-100 packages, respectively.

Appendix 2.12.5 of the application presents the dynamic foam properties used in the structural analysis of the impact limiter. These values represent the maximum allowable compressive strength values for the foam. Formulation, batch, and pour acceptance tests intended to ensure that the achieved foam properties are consistent with those used in the analysis are specified in Table 8-5. However, staff noted that the required density noted in Table 8-5 is incorrect. Staff included a CoC condition, clarifying that the required nominal density for all acceptance tests is 18, 8, and 11 lbs/ft^3 for Model Nos. AOS-025, AOS-050, and AOS-100, respectively. Additionally, staff noted that the acceptance test density may deviate from the achieved density due to variations in processing methods, geometry, material, temperature, and humidity. Accordingly, staff included a CoC condition requiring that the weight of the foam in each impact limiter be measured and its average density calculated based on the known volume of foam fill. The average density of the foam in each impact limiter must be within +/- 15% of 18, 8, and 11 lbs/ft^3 for Model Nos. AOS-025, AOS-050, and AOS-100, respectively. With these additional conditions, the staff finds that the impact limiter material properties are acceptable.

The conductivity and specific heat of the three grades of foam was presented in Table 3-9 of the application. However, the listed densities were not updated to reflect the most current foam values, as noted in Table 3-9, footnote b. Staff has assessed this discrepancy and found that the variation will have an insignificant effect on the thermal analysis.

2.2.4 Chemical, Galvanic or Other Reactions

Section 2.2.2 of the application describes all the permanent and temporary dissimilar metal joints in the packaging.

There are six permanent dissimilar metal joints: 5 joints are between stainless steel and either tungsten or carbon steel, and one joint is between stainless steel and copper. When tungsten is used for shielding, Section 2.2.2 of the application states that the package construction limits moisture at the tungsten stainless steel boundary, thus preventing galvanic or other interactions. The staff finds this acceptable. When carbon steel is used, it is electroless nickel plated with a minimum thickness of 21μm, thus limiting the galvanic potential difference and preventing galvanic corrosion between the carbon steel and stainless steel. Regarding the joint between stainless steel and copper, the application states that the potential difference between stainless steel and copper is sufficiently low as to not produce galvanic effects. The staff concurs with this position.

The temporary dissimilar metal joints involve the contents, shoring devices, and cavity surfaces, as well as the lid seal: the radioactive material contents, in solid form, are placed in an inside container and shored with compatible materials that have a melting point over 1,000ºF. For the Model Nos. AOS-025 and AOS-100 packages, in the case of high quantities of Co-60, a tungsten liner or axial shielding plug is also used. The tungsten liners and axial shielding plugs are electroless plated with at least 21μm of nickel to preclude galvanic interaction between the tungsten and stainless steel. The application states that the duration of these temporary dissimilar metal joints as a jointed unit, the service life of their components, and the continuous operational inspection preclude galvanic corrosion from occurring or going undetected. The staff concurs with this position. Finally, the drying procedure in Section 7.1.3.2 of the application provides sufficient assurance that any water that might contribute to galvanic degradation will be eliminated.

2.2.5 Effects of Radiation

The effects of radiation are addressed in Section 2.2.3 of the application. The packaging is comprised of 300 series stainless steel, tungsten alloy or carbon steel, and nickel alloy (lid bolts), which are not significantly affected by radiation. The lid seal materials (silver and stainless steel) are also resistant to radiation. The port seal material (silicone O-ring) is the most vulnerable to radiation damage, but is replaced after each use. The impact limiters are composed of stainless steel, which is resistant to radiation, and polyurethane foam. The polyurethane foam could be affected by radiation, but manufacturer data shows that it remains unaffected up to a cumulative dose of 2×10^8 rad.

In considering all of the above, the staff finds that radiation will not significantly degrade the performance of the materials of the AOS Transport Packaging System.

Based on review of the statements and representations in the application, staff concludes that the materials have been adequately described and evaluated and the package is adequate to meet the requirements of 10 CFR Part 71.

2.3 Fabrication and Examination

The materials used for the packaging are procured in accordance with the standards described in Section 2.1.4 above, including QA plans and tests to verify the conformity of the materials with the standards as described in Sections 2.3.1.1 and 8.1.5 of the application. The staff finds the standards and testing acceptable.

The fabrication process is conducted by the fabricator in accordance with established procedures, documented, and verified at critical points by the purchaser. Forming and machining are performed in accordance with the drawings and within tolerances. Welded components are final machined, and all other components are also machined to final configuration as identified on the drawings. Fitting and assembling, including alignment of components to be welded, are to be done according to the drawings. The staff finds the fabrication process acceptable.

The examination program for the materials, fabrication, and design of the packaging are described in Section 2.3.2, Table 2-18, and in Section 8.1.5.2 (materials only) of the application. The stainless steel will be submitted for chemical and mechanical testing to ensure conformance with materials specifications, the tungsten alloy will be submitted for density verifications by UT, and the impact limiter foam will be tested as described in Table 8-5 of the application. To verify the quality of the fabrication, visual and dimensional inspection of all components, hydrostatic and helium leak testing of the assembly, and visual, penetrant and ultrasonic testing of the welds will be performed. Finally, leak testing, thermal transmission properties measurements, drop tests, and dose rate mapping will be performed to verify the design of the packaging. The staff finds that the combination of these examination programs is acceptable to confirm material properties and meet fabrication requirements.

2.4 General Standards for All Packages (10 CFR 71.43)

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 impact limiter attachment turnbuckles or latch pins are fitted with a wire tamper seal. Removal of the impact limiter is required to access radioactive contents, thereby damaging the seal if tampered with. Thus, the requirements of 10 CFR 71.43(b) are satisfied.

2.4.3 Positive Closure

Positive closure is demonstrated by the use of a bolted closure lid. Opening of the cask requires specialized tools and a power source therefore, inadvertent opening is not credible.

The package was adequately analyzed for maximum internal and external differential pressures as well as expected external and internal pressures during NCT and HAC. Thus, the requirements of 10 CFR 71.43(c) are satisfied.

2.4.4 Chemical and Galvanic Reactions

See Section 2.2 of this SER for compliance with 10 CFR 71.43(d).

2.4.5 Valves

The package does not use valves; therefore, the requirements of 10 CFR 71.43(e) do not apply.

2.4.6 Normal Conditions of Transport

See Section 2.6 of this SER for compliance with 10 CFR 71.43(f).

2.4.7 Temperature Requirement

See Section 3 of this SER for compliance with 10 CFR 71.43(g).

2.4.7 Continuous Venting

The package does not incorporate a continuous venting feature; therefore, the requirements of 10 CFR 71.43(h) are satisfied.

2.5 Lifting and Tie-Down Standards for All Packages (10 CFR 71.45)

2.5.1 Lifting Devices

The applicant evaluated the package against lifting by analyzing the effects of pretorque/preload, horizontal and vertical weight components, and the effects of the geometry. The evaluation shows that the package is capable of lifting the package in the intended manner, with a safety factor of at least three for all package configurations.

The staff finds that, since the trunnions are attached by bolts to the outside of the cask, failure of the lifting devices would not affect the containment and shielding functions of the package.

Staff reviewed the calculations and justifications presented by the applicant and found them acceptable. Therefore, the requirements of 10 CFR 71.45(a)(1) for lifting devices are satisfied.

2.5.2 Tie-Down Devices

The applicant presented analyses to demonstrate that the package would withstand static forces equal to (i) two times the loaded package weight in the vertical direction, (ii) ten times the loaded package weight in the horizontal plane along the direction of travel, and (iii) five times the weight in the horizontal plane perpendicular to the direction of travel.

While staff finds that the analyses presented in the application are insufficient to demonstrate compliance with regulatory requirements, staff also notes that the package incorporates tiedowns which are internal to the shipping cages. These devices are not structural parts of the packaging; hence, no structural feature is used as a tie-down device. Thus, the requirements of 10 CFR 71.45(b)(1) are not applicable.

2.6 Normal Conditions of Transport

The applicant addressed the requirements of 10 CFR 71.71 mainly through Finite Element (FE) analyses performed with the LIBRA code. Tables 2-4 through 2-6 of the application list the load cases and combinations for the analyses to show compliance with NCT. These load cases and combinations were developed according to Regulatory Guide 7.8.

2.6.1 Heat

The applicant demonstrated compliance with regulatory requirements by thermal and structural analyses. Results from appropriate thermal analyses were used as input to the structural analyses for consideration of thermal stresses, according to the loading combinations described in Regulatory Guide 7.8.

Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges and the effects of differential thermal expansion proved to be minimal. The requirements of 10 CFR 71.71(c)(1) are satisfied.

2.6.2 Cold

The package must be able to withstand an ambient temperature of -40°C (-40°F) in still air and in the shade. The applicant stated that low-temperature conditions do not affect the package because the construction materials either do not undergo embrittlement or have operating ranges within the regulatory temperature range. The cold condition was evaluated by the applicant with respect to internal pressure, allowable stresses, and differential thermal expansion. Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges and the effects of differential thermal expansion were minimal. The requirements of 10 CFR 71.71(c)(2) are satisfied.

2.6.3 Reduced External Pressure

Reduced external pressure is analyzed in load combination 104. The load combination includes internal design pressure in addition to a reduced external pressure of 3.5 psi (25 kPa) (see Table 2-4 of the application). Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges. Staff finds the requirements of 10 CFR 71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

The analysis for this condition was conducted in a similar manner to the Reduced External Pressure case. Load Combinations 106 and 107 addressed the regulatory condition. Under an increased external pressure of 20 psi (140 kPa), the structural behavior is bounded by the requirements of 10 CFR 71.61 which requires that this type of package be capable of withstanding an external pressure of 290 psi due to a head of water for a period of one hour. The staff finds that the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration

Vibration and shock loads were analyzed using a 3D model in three separate analyses. The vibration and shock loads are conservatively assumed to be:

- Load Case 221 – 10 g in the forward direction
- Load Case 222 – 5 g in the lateral direction
- Load Case 223 – 2 g in the vertical direction

In all three analyses, displacements were fixed at the trunnions, and the vertical displacement was fixed along the package and truck bed contact line. The fixed nodes were illustrated in Figure 2-15, “Fixed Points for Shock and Vibration Analyses.” The inertia loads were applied as body forces and the resultant stresses were combined from all three analyses. Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges. Staff finds the requirements of 10 CFR 71.71(c)(5) are satisfied.

2.6.6 Water Spray

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

2.6.7 Free Drop

The structural evaluation of the free drop was performed by analysis in load case 231. The analysis relied upon the load-displacement characteristics obtained from the 30-foot drop analysis results. Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges. Based on staff review of the information presented by the applicant, 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 gross weight of the package exceeds 110 lb (50 kg), in accordance with 10 CFR 71.71(c)(8).

2.6.9 Compression

The compression tests apply since the gross weight of the package does not exceed 11,000 lb (5,000 kg), in accordance with 10 CFR 71.71(c)(9). The compression load of 5 times the cask weight (Load Case 215) was analyzed using a 2D model. The compression force was applied to the top of the cask as a pressure loading. Staff reviewed the input files and stress results provided by the applicant. All stresses were within acceptable ranges. Staff finds that the requirements of 10 CFR 71.71(c)(9) are satisfied.

2.6.10 Penetration

The impact of a rod falling onto the package was analyzed in Load Case 216. The cask was modeled by the 2D model illustrated in Figure 2-67. No significant penetration damage is expected from this event; therefore, the staff finds that the package meets the intent of 10 CFR 71.71(c)(10).

2.7 Hypothetical Accident Conditions

The applicant addressed the requirements of 10 CFR 71.73 mainly through FE analyses performed with the LIBRA code. Tables 2-4 through 2-6 of the application list the load cases and combinations for the analyses which show compliance with HAC. These load cases and combinations were developed according to Regulatory Guide 7.8.

2.7.1 30-foot Free Drops

The applicant pursued a finite element approach to demonstrate compliance with the 30-foot free drops. The methodology consisted of two sequential quasi-static analyses. The first was application of deformation upon a model of the impact limiter considering the maximum potential energy and calculation of the reaction forces on the surfaces adjacent to the cask. The second step was application of the forces calculated from the first analysis upon a model of the cask.

The benchmarking for the finite element relied upon testing performed on specimens of prototype AOS-165 model, a larger scale model of the AOS package. The AOS-165 model had an outside diameter of approximately 46 in and a length of approximately 59 in. The complete package with impact limiters weighed approximately 38,500 lbs. Although acceleration data was obtained during testing, due to several challenges documented in Appendix 2.12.6 it was not utilized in the benchmarking approach. Instead, a qualitative approach comparing deformations was used.

The staff does not find the qualitative deformation approach adequate to provide reasonable assurance of the structural performance of a package. Deflection comparisons of test results and finite element models provided by the applicant in Section 2.7.1.1.3 of the application are stated to differ by 25% for the end drop, a very large amount. Similarly, the differential for the side drop averages versus the model is of 26%, and close to 20% for the slapdown. Staff also finds that the assumption in the modeling of the impact limiter, which establishes a fixed boundary condition at the interface with the cask body, is not an accurate representation of the actual physics of the drop condition.

However, staff finds reasonable assurance of the performance of the package under 30-foot drop conditions based on the following:

1) Primarily, the fact that the prototype AOS-165 specimen used in the testing was essentially undamaged after the drops. The same specimen was used for the three test drops (end drop, side drop, slapdown drop), which were applied sequentially using new impact limiters for each drop. The specimen retained a leak rate below $2.96.10^{-7}cm^3/sec$ (helium), at a differential pressure of 1 atmosphere in all cases. Given that the AOS package models are all scale models of the same design, it is expected that they would all perform similarly.

2) The impact limiters of the prototype AOS-165 specimen were constructed with 20 pcf foam. The accelerations imparted during the drop events are related to the density characteristics of the impact limiter foam. The AOS models use impact limiters with foam density equal to or less than the AOS-165 prototype, therefore it is expected that the loads due to accelerations would obey scaling laws and be (in a scaled sense) equally or less severe than the ones experienced by the test specimens.

3) The finite element modeling, although not completely accurate in the physical representation of the casks, still presented a conservative loading, given the consideration of the complete potential energy of the drop scenario. For the lid bolt analyses, an additional factor of 1.15 was used to increase the loading. In addition, all computed stresses were well within the required margins of safety according to Regulatory Guide 7.6.

4) The applicant provided comparisons of static and dynamic analyses using the LIBRA finite element code in Section 2.12.9 of the application. The static analyses compared well with the dynamic analyses, thus providing added assurance of the adequacy of load level.

Staff finds that the package satisfies the requirements of 10 CFR 71.73(c)(1).

2.7.2 Crush

The regulatory requirement for crush was evaluated for the Model Nos. AOS-025A, and AOS-050 packages. For the Model No. AOS-100, this evaluation is not applicable due to the package mass exceeding 1,100 lbs. The compression load of 5 times (5x) the cask weight, Load Case 215, was analyzed using a 2D finite element model. Staff reviewed the input files and stress results provided by the applicant. All stresses far exceeded minimum safety margins. Staff finds that the requirements of 10 CFR 71.73(c)(2) are met.

2.7.3 Puncture

The package is evaluated for accidental drops in Load case 311. The Model Nos. AOS-025A, AOS-050A, and AOS-100A packages are analyzed for 4-foot drop onto a 6-in diameter steel bar. The orientation for the event was vertically through the center of the impact limiter. Although a potentially more damaging configuration could exist for the Model No. AOS-050 through direct impact with the portion of the package which is not covered by the impact limiter, this portion of the package is away from the containment, and is unlikely to result in any significant damage to the package. The same applies to the Model No. AOS-100, which is even thicker and stronger, while the Model No. AOS-025 is completely covered by the impact limiters. Staff reviewed the analyses presented by the applicant and finds that the requirements of 10 CFR 71.73(c)(3) are met.

2.7.4 Thermal

The applicant utilized temperature information from the LIBRA fire event thermal analyses as input for the structural analyses. The structural analyses considered the pressures developed from the thermal event. Staff reviewed the input files and stress results provided by the applicant. All stresses far exceeded minimum safety margins, therefore the requirements of 10 CFR 71.73(c)(4) are met.

2.7.5 Immersion - Fissile

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

2.7.6 Immersion - All Packages

This condition is less demanding to the transport packages than the Deep Water Immersion condition, and is therefore covered by the Deep Water condition. All AOS models are analyzed to the Deep Water condition. Therefore, the requirements of 10 CFR 71.73(c)(6) are met.

2.7.7 Deep Water Immersion (For Type B Packages Containing More than 10^5 A_2)

The Deep Water condition was evaluated by finite element analysis with a pressure load of 290 psia. This condition, represented by Load Case 204, was analyzed by the use of a 2D cask model. Pressure is applied to the model outside the package surface. Staff reviewed the input files and stress results provided by the applicant. All stresses comply with minimum safety margins, therefore the requirements of 10 CFR 71.61 are satisfied.

2.8 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the structural design has been adequately described and evaluated and that the package has adequate structural integrity to meet the requirements of 10 CFR Part 71.

3.0 THERMAL REVIEW

The Model Nos. AOS-25A, AOS-50A, AOS-100A, AOS-100A-S, and AOS-100B packages are Type B packages designed to transport solid radioactive materials in Normal and Special form. The isotopes and their respective activity limits for each package model are listed in Table No. 2 of the application.

3.1 Thermal Design Features

The structural members of the packaging are 300 series stainless steel with carbon steel or tungsten embedded within the cask and lid plug for shielding. The impact limiters are a 300 series stainless steel thin shell filled with polyurethane foam – General Plastics LAST-A-FOAM FR-3700 series. Impact limiters fully surround the Model No. AOS-25A package, which can be seen to some degree in Figure 1-1 of the application, while they partially surround each of the

Model Nos. AOS-50A and AOS-100A, AOS-100A-S, and AOS-100B packages, as seen in Figures 1-2 and 1-3 of the application. The lid seal is a metallic, double "C" cross-section – Garlock Helicoflex metallic seal with an alloy 90 spring and silver jacket. Test port, vent and drain port seals are Parker silicone (S1224-70). The packaging design does not require specific arrangement of the contents within the cavity for thermal performance. Baskets or racks that are made of aluminum or stainless steel can be used to shore payload. The personnel barrier is an aluminum frame, with five aluminum mesh or screen panels. The personnel barrier fully encloses each of the AOS models attaching to the transport pallet for the AOS-25A and AOS-50A models or a truck bed for each of the three AOS-100 models.

3.1.1 Decay Heat

The Model No. AOS-25A package is limited to a decay heat of 10 Watts while the Model No. AOS-50A package is limited to a decay heat of 100 Watts. The Model Nos. AOS-100A, AOS-100A-S, and AOS-100B packages are each limited to a decay heat of 400 Watts as seen in Table 1-3 of the application.

3.1.2 Summary Tables of Temperatures

Table No. 3 below provides a summary of component temperatures for the Model No. AOS-25A package NCT (with maximum decay heat and solar load) and HAC analyses conducted by the applicant. Table 3 shows that the maximum calculated component temperatures are within the applicable temperature limits.

Table No. 3: AOS-25A Maximum Temperatures for NCT and HAC

Component	NCT (°F)	HAC (°F)	Maximum Allowable	
			NCT (°F)	HAC (°F)
Outside Shell	256	294	1000	1000
Inside Shell (Cask Cavity)	257	277	1000	1000
Lid	255	274	1000	1000
Lid Plug	258	277	1000	1000
Bottom Plate	255	279	1000	1000
Shielding	256	276	1000	1000
Lid Seal	255	274	572	572
Test Port	255	274	450	450
Drain Port	255	276	450	450
Vent Port	255	274	450	450
Impact Limiter Foam	202	N/A	260	N/A
Accessible Outside Surface in Shade	119	N/A	122 (non-exclusive use) 185 (exclusive use)	N/A

Table No. 4 shown below provides a summary of component temperatures for the Model No. AOS-50A package NCT (with maximum decay heat and solar load) and HAC analyses conducted by the applicant. Table 4 shows that the maximum calculated component temperatures are within the applicable temperature limits. While the elastomeric seals for the test, drain, and vent ports appear to be close to their maximum allowable limit for the Model No. AOS-50 during HAC, the HAC limit provided is a continuous operating limit, and short term limits for silicone are significantly higher according to the Parker O-ring Handbook. From the applicant's analysis, the elastomeric seals will be at that maximum HAC temperature for approximately 15 minutes during the post-fire cool down.

Table No. 4: AOS-50A Maximum Temperatures for NCT and HAC				
Component	NCT (°F)	HAC (°F)	Maximum Allowable	
			NCT (°F)	HAC (°F)
Outside Shell	287	777	1000	1000
Inside Shell (cask cavity)	296	499	1000	1000
Lid	286	433	1000	1000
Lid Plug	298	446	1000	1000
Bottom Plate	286	435	1000	1000
Shielding	288	504	1000	1000
Lid Seal	286	434	572	572
Test Port	284	433	450	450
Drain Port	286	440	450	450
Vent Port	286	437	450	450
Impact Limiter Foam	242	N/A	260	N/A
Accessible Outside Surface in Shade	113	N/A	122 (non-exclusive use) 185 (exclusive use)	N/A

Table No. 5 shown below provides a summary of component temperatures for the Model Nos. AOS-100A and AOS-100A-S packages NCT (with maximum decay heat and solar load) and HAC analyses conducted by the applicant. Table No. 5 shows that the maximum calculated component temperatures are within the applicable temperature limits.

Table No. 5: AOS-100A and AOS-100A-S Maximum Temperatures for NCT and HAC				
Component	NCT (°F)	HAC (°F)	Maximum Allowable	
			NCT (°F)	HAC (°F)
Outside Shell	295	866	1000	1000
Inside Shell (cask cavity)	312	476	1000	1000
Lid	294	403	1000	1000
Lid Plug	317	426	1000	1000
Bottom Plate	294	405	1000	1000
Shielding	298	475	1000	1000
Lid Seal	293	404	572	572
Test Port	293	402	450	450
Drain Port	291	410	450	450
Vent Port	290	407	450	450
Impact Limiter Foam	231	N/A	260	N/A
Accessible Outside Surface in Shade	106	N/A	122 (non-exclusive use) 185 (exclusive use)	N/A

Table No. 6 shown below provides a summary of component temperatures for the Model No. AOS-100B package NCT (with maximum decay heat and solar load) and HAC analyses conducted by the applicant. Table No. 6 shows that the maximum calculated component temperatures are within the applicable temperature limits.

Table No. 6: AOS-100B Maximum Temperatures for NCT and HAC				
Component	NCT (°F)	HAC (°F)	Maximum Allowable	
			NCT (°F)	HAC (°F)
Outside Shell	295	866	1000	1000
Inside Shell (cask cavity)	312	467	1000	1000
Lid	294	398	1000	1000
Lid Plug	317	421	1000	1000
Bottom Plate	294	401	1000	1000
Shielding	298	467	1000	1000
Lid Seal	293	399	572	572
Test Port	293	397	450	450
Drain Port	291	405	450	450
Vent Port	290	403	450	450
Impact Limiter Foam	231	N/A	260	N/A
Accessible Outside Surface in Shade	106	N/A	122 (non-exclusive use) 185 (exclusive use)	N/A

3.1.3 Summary Tables of Maximum Pressures in the Containment System

Table No. 7 shown below provides a summary of maximum normal operating pressures (MNOP) during NCT for each of the models. All pressures were calculated based on the ideal gas law using the maximum cavity temperature for NCT, and the staff confirmed these calculations. Table No. 3.5 shows that the MNOP is within the design pressure for each of the models.

Table No. 7: MNOP in the Containment System			
Model	Temperature (°F)	Pressure (psia)	Design Pressure (psia)
AOS-25A	257	20	30
AOS-50A	296	21	60
AOS-100A, AOS-100A-S	312	21	280
AOS-100B	312	21	280

Table No. 8 shown below provides a summary of maximum pressures during HAC for each of the models. All pressures were calculated based on the ideal gas law using the maximum cavity temperature for HAC, and the staff confirmed these calculations.

Table No. 8 shows that the maximum pressure during hypothetical accident conditions is within the design pressure for each of the models.

Table No. 8: Maximum Pressure in the Containment System During Hypothetical Accident Conditions			
Model	**Temperature (°F)**	**Pressure (psia)**	**Design Pressure (psia)**
AOS-25A	277	20	30
AOS-50A	495	26	60
AOS-100A, AOS-100A-S	461	25	280
AOS-100B	478	26	280

3.2 Material Properties

The applicant provided material properties in the form of thermal conductivities, densities, and specific heats for the modeled components of the package. The staff reviewed the thermal properties used for the analysis of the package as discussed In Section 2.2 above. The staff determined that the values used were appropriate for the materials specified.

3.2.1 Component Specifications

The package lid seals, supplied by Garlock Helicoflex, are metallic seals that have a silver jacket surrounding an alloy 90 spring and have minimum and maximum temperature ratings of -40°F and 572°F, respectively. The containment boundary test port, vent port, and drain port seals are Parker O-rings (S1224-70) with minimum and maximum temperature ratings of -65°F and 450°F respectively.

3.3 Thermal Evaluation for Normal Conditions of Transport

3.3.1 Evaluation by Analysis

The staff confirmed that the methods used for the thermal analyses were identified and sufficiently described to permit a complete and independent verification. The applicant used the LIBRA finite element analysis code to perform the thermal evaluation of the packages.

The applicant assembled several analysis models of the packages to determine the temperatures that the components would experience during NCT and HAC conditions. The models are described below.

3.3.2 Thermal Models

The thermal models for the Model Nos. AOS-25A, AOS-50A, AOS-100A, AOS-100A-S, and AOS-100B packages are 2 dimensional axisymmetric models and include the complete package length. Each model includes the geometry and material properties of the impact limiters, outside shell, cavity shell, lid, lid plug, end plate, and shielding. The outside shell, cavity shell, lid, lid plug, end plate, and shielding are modeled with four-node conduction elements. Section 3.3.3.1 of the application shows how a uniform heat flux on the interior of the cask cavity using two-node convective boundary elements to represent the decay heat of the contents is applied to the models. Section 3.5.6 of the application provides a sensitivity study based on different distributions of decay heat within the package cavity. The sensitivity study indicates that temperatures vary little with changes in the decay heat distribution (See Section

3.5.6 of this SER for further discussion). The staff believes that the applicant's assumption of uniform decay heat produces conservative temperatures for modeled components, but may not be conservative for the radioactive contents, basket, or shielding liners that were not modeled; however, the choice not to model the radioactive contents, basket, or shielding liners does not pose a safety concern due to the relatively low decay heat of the contents, and the comparatively high temperature limit of the shielding material.

All gaps, filled with air or stainless steel wool, used in the model were specified in the application and can be seen in Figure 3-4 of the application. Staff notes that the Model No. AOS-25A package is fully enclosed by the impact limiters. Air gaps are modeled with two-node conduction elements and have conduction and radiation properties. Further detail on how the air gaps have been thermally modeled is provided in Section 3.3.3.2 of the application. During NCT, nominal air gap dimensions were increased by 0.01 inch, the drawing tolerance, and contact resistance for components in complete contact was increased by a factor of ten from the nominal value. The stainless steel outer surface of the impact limiters is modeled with two-node conduction elements while the LAST-A-FOAM interior is modeled with four-node conduction elements.

Two-node boundary elements define the convective and radiative properties at the interface between the outer surface and the environment at 100°F. These boundaries are also where the solar heat flux is applied. For each surface of the thermal model, an effective film coefficient as a function of surface temperature is calculated for the regulatory ambient conditions and is shown in Table 3-14 of the application. The effective film coefficient equation is the addition of the radiative and convective heat transfer coefficients. The applicant has provided equations for the convective heat transfer coefficients to be used for vertical and horizontal surfaces and horizontal cylinders. For vertical cylinders (like surfaces on the Model Nos. AOS-25A and AOS-50A), it can be assumed that curved vertical surfaces are flat plates if the length is sufficiently small compared to the diameter. The radiation heat transfer coefficient is defined in Section 3.3.3.2 of the application.

The solar heat load boundary conditions are defined and shown in Section 3.3.3.7 of the application. Review of the applicant's thermal models determined that the applicant conservatively applied the solar heat load continuously. While one surface for the Model No. AOS-50 package was technically below the regulatory limit in 10 CFR 71.71(c)(1) because it is a flat horizontal surface that is not a base, since it is the exposed underside surface of the upper impact limiter, it is not seeing full sun as a typical horizontal surface would and the staff believes that the approximation used is reasonable. The staff also believes applying continuous solar insolation to the other surfaces makes up for the one surface being below the regulatory limit. For the Model Nos. AOS-25A and AOS-50A packages, transported vertically, there is no convection, radiation, or solar insolation applied to the base surfaces.

3.4 Thermal Evaluation for Hypothetical Accident Conditions

3.4.1 Initial Conditions

The initial boundary conditions for the fire are NCT at 38°C (100°F) ambient temperature with maximum decay heat and solar load. The applicant modified the AOS-25A, AOS-50A, AOS-100A, AOS-100A-S, and AOS-100B LIBRA thermal models used for NCT to include impact limiter damage from the HAC drop tests. Equivalent convection and radiation was applied to the external surfaces at 100°F according to Table 3-14 of the application. Impact limiter foam density and conductivity were modified according to Table 3-9 of the application based on the reduced volume of the impact limiters. The models were then run to steady state.

3.4.2 Fire Test Conditions

The models were then exposed to a 30 minute fire at 800°C (1475°F) with an emissivity = 0.9 and a surface absorptivity = 0.8. The convective heat transfer coefficient is 10 W/(m^2°C). The above boundary conditions were applied in the form of an effective film coefficient equation as described in Section 3.3.3.8 of the application. The thermal models include reduced impact limiters that account for deformations applied simultaneously based on head-on, side, and corner 9 m (30 ft) drops of the Model No. AOS-165 as well as crush tests of the Model Nos. AOS-25 and AOS-50 packages from the initial conditions. LAST-A-FOAM properties remain the same as the initial conditions for the fire based on HAC drop impact limiter reduced volume. During HAC all air gaps were closed and contact resistance for components under complete contact was decreased by a factor of ten from the nominal value.

The post-fire cool down analysis with maximum decay heat and solar insolation lasted for 7.5 hours after the end of the fire. Equivalent convection and radiation was applied to the external surfaces at 100°F according to Table 3-14 of the application. All models were assumed to have the same orientation during the post-fire as they had during NCT (vertical for the Model Nos. AOS-25 and AOS-50, horizontal for the Model Nos. AOS-100A and AOS-100B). Therefore convection, radiation, and solar insolation were not applied to the base of the Model Nos. AOS-25 and AOS-50. During the post-fire cool down, the gaps and contact resistance were changed back to NCT values. Also during the post-fire cool down, the impact limiter foam was assumed to be destroyed and the material properties were replaced by air. During the post-fire, component temperatures reach a maximum and return to steady state values as can be seen in Figure 3-72 through Figure 3-74 of the application for the Model Nos. AOS-100A and AOS-100A-S.

3.4.3 Maximum Temperatures and Pressures

Maximum temperatures during NCT and HAC for the Model Nos. AOS-25A, AOS-50A, AOS-100A/A-S, and AOS-100B packages are shown in Tables 3. 4, 5, and 6 respectively of this SER. Maximum pressures for the Model Nos. AOS-25A, AOS-50A, AOS-100A, AOS-100A-S, and AOS-100B packages during NCT and HAC are shown in Tables 7 and 8 respectively of this SER.

3.4.4 Maximum Thermal Stresses

Thermal stresses resulting from temperature gradients and differential thermal expansion are provided in Sections 2.6.1 and 2.7.4 of the application.

3.5 Appendices

3.5.1 Data

The applicant provided LIBRA thermal model files for the Model Nos. AOS-25, AOS-50, and AOS-100 packages. The staff focused the review of the packages on the NCT (100°F ambient, maximum decay heat, and solar insolation), fire (1475°F ambient with maximum decay heat for 30 minutes), and post-fire cooldown (100°F ambient with maximum decay heat, and solar insolation) models.

3.5.2 Thermal Evaluation Results – Model Nos. AOS-25, AOS-50, and AOS-100

The applicant presented temperature plots and maximum component temperatures for each of the four models during various thermal load case conditions, as well as temperature vs. time profiles for key components during the fire and post-fire cool down analysis. The staff focused their review on NCT (100°F ambient, maximum decay heat, and solar insolation), fire (1475°F ambient with maximum decay heat for 30 minutes), and post-fire cooldown (100°F ambient with maximum decay heat, and solar insolation) models.

3.5.3 LIBRA Finite Element Program Heat Transfer Module

Appendix 3.5.3 of the application describes the LIBRA heat transfer program which is capable of performing 2-D and 3-D steady-state and transient analyses. The heat transfer code is compatible with the structural code in that similar models can be used and temperatures can be applied to the structural model. The program was verified against exact solution problems listed in Table 3-76 of the application.

A thermal test was performed on the GE Model 2000 transport package to provide benchmark data with the LIBRA results. The LIBRA calculated temperature patterns correlate well with test results.

3.5.4 Analysis Modeling Data

The applicant presented thermal material properties references for SS304, tungsten alloy, SA-105 carbon steel, and air. Values for density, thermal conductivity, and specific heat compared well to the values presented in Section 3.2.1 of the application. Overall NCT model dimensions were provided in order to compare to the HAC thermal models that showed HAC impact limiter damage from head-on analysis. The applicant performed a sensitivity study (in Section 3.5.4.2.5 of the application) which demonstrated that the HAC damage combination of 100% of the deformation for the head-on impact, side/crush impact, and cg over corner impact produced higher temperatures (in the order of 6 – 12°F higher) than a HAC model with 100% of the deformation for the head-on impact. The applicant discussed conduction across enclosed air gaps, also addressed in Section 3.3.3.2 of the application. The applicant showed the use of an approximation for radiative heat transfer across the enclosed air gaps as a function of one temperature. The staff performed a sample calculation for radiative heat transfer with a representative air gap temperature difference and found that the approximation was appropriate. Reviewing the tables of conductivity values as a function of temperature across the air gaps, the staff also recognized that the contribution of radiative heat transfer across the gap was not significant compared to the conductivity of air.

Further details including surface shape, size, orientation, and ambient temperature were provided in Section 3.5.4.5 on the external surface convective coefficients for all models during NCT and HAC. These polynomial coefficients include convective and radiative heat transfer as a function of surface temperature. The staff performed a few sample calculations and found them to be accurate. It also appears the applicant applied conservatively large values for some of the characteristic length values which yield smaller convective coefficients.

The applicant provided sample calculations to show that a vertical cylinder may be treated as a vertical flat plate for the Model Nos. AOS-25 and AOS-50 in Section 3.5.4.6 of the application. The staff confirmed these calculations for NCT conditions and confirmed that the methodology applied to the post-fire analysis as well.

3.5.5 LIBRA File Input Showing Material Property Assignation

Section 3.5.5 is a LIBRA thermal input file and shows how thermal material properties provided in the application are used in a LIBRA input file. These were reviewed by staff for consistency and accuracy. No major discrepancies were noted.

3.5.6 Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity

In Section 3.5.6, the applicant provided results from two additional cases where the decay heat was varied from the baseline uniform distribution throughout the cask cavity. Case 1 was the baseline showing uniform distribution, case 2 was varied from the baseline such that the cask cylindrical surface receives twice the decay heat of the top and bottom, and in case 3 only the cask cylindrical surface receives the entire decay heat. The results showed that the baseline uniform distribution produced the maximum component temperatures. The applicant also addressed thermal stresses in relation to uniform decay heat stating that a change in uniform decay heat distribution would have a negligible effect on overall stress evaluations.

3.5.7 Thermal Tests

Section 3.5.7 of the application describes the thermal test setup for the Model No. AOS-165A, a larger model not approved for transport in this application. The test cask consisted of the outside shell, cavity shell, lid, bottom plate, and tungsten shielding. The cask was placed inside a pit on top of a steel pedestal with a steel wool insulation pad between the bottom surface of the package and the pedestal. An electrical heat source was placed inside the cavity. Thermocouple locations are shown in Figure 3-189 of the application and Figure 3-191 shows the package inside the pit. During the heating cycle, the heater was set to 7000 Watts and temperatures were recorded in one minute intervals during the transient event until the package temperatures remained unchanged for one hour. The heater was turned off during the cool down cycle and temperatures were recorded in one minute intervals until the package reached ambient temperature. Thermocouple heatup and cooldown temperature vs. time plots are shown in Figures 3-192 through 3-195 of the application. A 2D axisymmetric model, see Figure 3-196 of the application, was created to verify the test results. Thermal model contact resistance and gaps between cask component interfaces are also described in Section 3.5.7.2 of the application. The test results were compared with the results of the analytical model subjected to the same environment. Boundary conditions during heatup and cooldown are shown in Figures 3.197 and 3.198 of the application, respectively. A comparison of thermocouple and 2D model temperatures are shown in Figures 3-199 through 3-206 of the application.

3.5.8 Heat Test Report – AOS-165A Prototype

The heat test report for thermal conductivity testing on the AOS-165A provides further details regarding the type and location of thermocouples, heater specifications, as well as test equipment, with the objective to provide transient and steady state temperature data for a known heater input for verifying modeling of the cask. Section 4.5 of the test report shows steady state temperatures reached during the two heat rise tests, while Section 4.6 shows the final thermocouple values for the heat decay test. Appendices A through C of the test report show tabulated thermocouple data from the two heat rise tests and heat decay test, respectively. Temperature vs. time charts for each thermocouple are shown for each of the three tests in Appendices D through F of the test report.

The staff notes that there are some general differences between the AOS models presented in Chapter 3 and the model used in the heat test as presented in the Heat Test Report in Section 3.5.8 of the application. The lid plug insert was not used during the heat test due to insufficient clearance between the lid plug insert and the cask (See comparison of Figures 1 and 2 of the Heat Test Report). While the electric heater was 7000 +/- 70 Watts, the power appeared to be much more likely to be below 7000 Watts than above based on looking at the power calculated every minute during the two heat up heat test runs.

The applicant performed the heat up and started the cooldown, but during the cooldown noted that the data logger had been stopped at the beginning of the cooldown. The applicant performed the heat up again to allow the package to reach steady state. The staff notes that thermocouple 8 showed erratic behavior during both heat run tests due to a fractured junction. It appeared from looking at Figure 2 of the Heat Test Report, that thermocouple 8 temperatures should have been similar to thermocouple 7 and therefore the staff concluded its loss was not significant.

The staff also notes that while it is acceptable not to thermally model the contents for the Model Nos. AOS-25, AOS-50, and AOS-100 packages due to the relatively low decay heat and the type of contents being transported, this report shows the temperature of thermocouple 1 at the center of the electric heater reaches approximately 1200°F (see Figure 2 of the Heat Test Report), significantly higher than the temperature of the cask cavity wall from thermocouple 7 (560°F). In any future applications, depending on the decay heat, contents, and shielding material, the cavity contents, basket, and shielding material should be explicitly modeled rather than applying a uniform decay heat to the cavity walls.

3.6 Conclusions

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

4.0 CONTAINMENT REVIEW

The staff reviewed the package containment design to verify that it has been adequately described and evaluated under NCT and HAC, as required per 10 CFR Part 71.

4.1 Description of the Containment System

4.1.1 Containment Boundary

The containment system of the Model Nos. AOS-25, AOS-50, and AOS-100 packages is described in Section 4.1.1 of the application and consists of the following components: (1) the packaging cavity shell, (2) containment penetrations or port plug sub-assemblies, (3) lid seal components and (4) lid attachment bolts.

Table No. 9 lists the containment system components and their material of construction.

Table No. 9

Containment System Components

AOS Containment System Components		
Part	**Item No. from Packaging Parts List 166D8143, REV. C**	**MATERIAL**
Packaging Cavity Shell	3	300 Series SS
Packaging Lid	2	300 Series SS
Lid Seal	14	Silver Jacket, Alloy 90 Spring
O-Ring (port plug)	19 & 29	Silicone (Parker S1224-70)

There are three containment penetrations in the package design – the drain and vent ports and a cask lid penetration. These ports are comprised of a lower seal, a threaded pipe plug, a silicone material O-Ring, and a port cap. Each penetration is designed to maintain a leakage rate of 1×10^{-7} ref-cm^3/sec or less, which is defined as "leak tight" per ANSI N14.5.

The package's lid is secured to the packaging body with 8 ASME SB-637, Grade N07718, 3/16 inch diameter bolts, with torque values as indicated in Table 7-2 of the application. The vent and drain ports are each closed with a single socket screw and a seal.

The staff reviewed the containment system description and concludes that the description of the containment boundary is sufficient in detail to provide an adequate basis for its evaluation, per the requirements of 10 CFR 71.31(a)(1) and 10 CFR 71.33(a)(4). The staff also finds that the containment system is securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package, as required by 10 CFR 71.43(c).

4.1.2 Codes and Standards

The materials of construction used on the package containment boundary meet ASME Code requirements (Section III, Division 1), with the exception of the lid seal materials. Table 2-18 of the application provides a listing of the codes and standards used for the design, fabrication, examination, and testing of the packages. The materials used for the fabrication of the components of the packaging are in general accordance with the applicable rules of ASME Section II, Parts A, B, and C, as applicable.

The staff has reviewed the description of the containment system, as described in Chapter 4 of the application. The staff concludes that the established codes and standards applicable to the containment design have been identified per the requirements of 10 CFR 71.31(c).

4.2 Containment under NCT

4.2.1 Pressurization of Containment Vessel

Table 4-6 of the application provides a summary of the calculated operating pressure of the various models of the packages for NCT. In summary, the MNOP for the Model Nos. AOS-25A, AOS-50A, and all variants of the AOS-100 packages are 20, 21, and 21 psia, respectively. This is within the design pressures of 30, 60, and 280 psia, respectively.

4.2.2 Containment Criteria

The containment system is designed to a leakage rate of 1×10^{-7} ref-cm^3 /sec or less. In accordance with ANSI N14.5, fabrication verification, periodic verification, and assembly verification leak tests will be performed to verify the containment capability of the containment system.

4.2.3 Compliance with Containment Criteria

Results of the applicant's structural and thermal analyses show that the containment system retains the capability to maintain a seal of 1×10^{-7} ref-cm^3/sec or less under the conditions specified in 10 CFR 71.71, which is considered leak tight per ANS/ANSI N14.5. Therefore, the staff concludes that the loss or dispersal of radioactive material from the cask will be less than 10^{-6} A_2 per hour under NCT, as required in 10 CFR 71.51(a)(1).

4.3 Containment under HAC

4.3.1 Pressurization of Containment Vessel

Table 4-7 of the application provides a summary of the calculated operating pressure of the various models of the packages for accident conditions (specifically the HAC fire). In summary, the accident pressures for the Model Nos. AOS-25, AOS-50, and AOS-100 packages are 20, 26, and 25 psia, respectively. This is within the design pressures for the packages.

4.3.2 Containment Criteria

The containment system is designed to a leakage rate of 1×10^{-7} ref-cm^3/sec or less under hypothetical accident conditions.

4.3.3 Compliance with Containment Criteria

Results of the thermal analysis presented in Table 3-4 of the application show that seal temperatures will remain below the seal material temperature limits of 300 F during and after the 30-minute fire. Results of the structural analyses for the AOS series of packages demonstrate that the cask inner shell for all the AOS package types will not buckle under HAC.

Results of the structural and thermal analyses in Chapters 2 and 3 of the application demonstrated that the containment system remained leak tight under the tests specified in 10 CFR 71.73. Since the containment vessel is designed, fabricated, and tested to meet the leak tight criteria of ANSI N14.5-1997, there is no contribution to the radiological consequences due to a potential release of canister contents. The staff agrees with the applicant's conclusion that the containment system meets the requirements of 10 CFR 71.51(a)(2).

4.4 Evaluation Findings

Based on review of the statements and representations in the application, the staff has reasonable assurance that the containment design of the AOS series of packages has been adequately described and evaluated and that the packages meet the containment performance requirements of 10 CFR Part 71.

5.0 SHIELDING REVIEW

The applicant provided an evaluation of the shielding characteristics of the packages and documented it in Chapter 5 of the application. The staff's evaluation is based on the October 2011 application, Revision E. There is no difference pertaining to the shielding evaluation between Revision Nos. E and F of the application. The staff used the guidance in Section 5 of NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material" (March 1999).

5.1 Description of the Shielding Design

5.1.1 Design Features

The staff reviewed the General Information Chapter (Chapter 1) of the application and the information in the Shielding Chapter (Chapter 5) of the application. The primary shielding features of the package is the tungsten (for "A" designations) or carbon steel (for "B" designations) radial and axial gamma shields. The Model No. AOS-025A package also includes an additional tungsten liner inside the cavity. The Model No. AOS-100 package has additional tungsten axial shielding plates for use when shipping higher amounts of Co-60 as specified in Table 1-2 of the application.

The staff verified that the applicant provided adequate information to describe the dimensions, tolerances, and densities of the gamma shielding material. The density of the gamma shield materials are listed in Table 5-3 of the application.

There is no neutron shield material present in the package. The applicant stated that neutron emitting materials will not be shipped.

There is no specific arrangement of the contents required with respect to shielding performance since the analysis was done using a conservative geometry.

5.1.2 Summary Table of Maximum Radiation Levels

The staff reviewed the summary Tables 5-4 and 5-5 of the application as well as the calculated dose rates in Tables 5-11, 5-12, 5-13, and 5-14 and determined that the values are within the limits of 10 CFR 71.47 and 10 CFR 71.51 for both NCT and HAC.

5.2 Radiation Source

The package is designed to ship specific source material including Co-60, Cs-137, Hf-181, Ir-192, Zr/Nb-95, Ho-166, and Yb-169. The staff confirmed that the activity used in the shielding analysis is consistent or conservative with respect to that specified in Table 1-2 in the General Information section of the application.

5.2.1 Gamma Source

The applicant obtained the source spectra for each radionuclide using the ORIGEN-ARP library with the exception of Ir-192 and Zr/Nb-95. For Ir-192 the applicant used the spectra from the Table of Nuclides (Korea Atomic Energy Research Institute, Table of Nuclides, accessed

September 2006) because this spectra was more conservative. For Zr/Nb-95, the applicant assumed the Zr and Nb are in equilibrium and provided information demonstrating that this is conservative. The analysis spectra for all of the proposed contents is in Table 5-18 of the application. The staff reviewed these emissions by comparing them to data from ICRP Publication 38, "Radionuclide Transformations Energy and Intensity of Emissions" (Reference 5-1). The staff found that the applicant's spectra is equivalent or more conservative. The staff found the spectra used by the applicant acceptable.

5.2.2 Neutron Source

The applicant does not propose to ship any neutron emitting material.

5.3 Shielding Model

The staff reviewed the information in the Structural (Chapter 2) and the Thermal (Chapter 3) sections of the application as it pertains to the shielding evaluation. The applicant used the impact limiter as the package surface and accounts for the deformation due to NCT. The applicant states that during HAC any damage that occurs to the package is limited to the impact limiter. All HAC dose point locations were referenced from the cask surface, i.e., neglecting the impact limiter altogether. The staff found this conservative and acceptable.

Streaming paths are neglected by the applicant. The staff found this acceptable. The geometry of the packages is such that there are no substantial streaming paths. The staff also found that conservatisms included in the shielding analyses are enough to compensate for any minor streaming.

5.3.1 Configuration of Source and Shielding

The applicant uses nominal dimensions for the packaging. Considering the calculated dose rates for the packages and other conservative analysis assumptions (the calculated dose rates show a 10% margin until regulatory dose rates are exceeded), the staff found that the uncertainty of considering design tolerances would not be enough for the packages to exceed any regulatory dose rate limits and therefore found it acceptable.

The applicant assumed the radioactive material is a point source adjacent to the interior cavity wall. The applicant calculates both the axial and radial dose by assuming the source is adjacent to either the axial or the radial wall. The staff found this geometry configuration conservative because it maximizes the intensity of the emissions. A point source eliminates self shielding and since the source was placed on the interior wall, this minimized the distance between the source and the detector.

In a supplement to the application the applicant demonstrated that the point source will always be conservative versus a line source. Therefore the staff found the use of the point source approximation acceptable.

The applicant models the dose point locations as a point detector with the least amount of shielding between it and the source. The staff found that this assumption will give conservative radiation levels and is therefore acceptable.

The packages will include a personnel barrier, however, since these can be shipped as nonexclusive use packages and the personnel barrier has not been subjected to the NCT tests in 10 CFR 71.71, the applicant defines the external surface of the package as the impact limiter. The applicant included a dose point at the impact limiter as well as 1 meter from the cask surface and 1 meter from the impact limiter. In these analyses the applicant assumes the impact limiter surface to be that of the deformed impact limiter as a result of NCT. They accounted for the side (radial) and end (axial) drop. The applicant states that these bound the corner drop. The staff verified the assumed deformation with the information in Chapter 2 of the application and found that it is conservative.

The impact limiter does not cover the entire axial length of the package for AOS-50, or AOS-100 models. With the exception of Co-60-B quantities within the AOS-100 where additional axial shielding is used, all dose rates for all contents for the AOS-50 and AOS-100 models are highest in the axial direction. The dose rates for Co-60-B quantities are highest in the radial direction at 1m (i.e. the transport index cannot exceed 10). The staff performed calculations for Co-60-B amounts referencing from the cask surface instead of the deformed impact limiter surface. At 1 meter, the staff's calculations showed that there would be approximately a 30% increase in dose rates. The personnel barrier, even though it does not serve a structural function, would also prevent personnel from accessing the surface of the package. The staff considered this and the conservatisms in the shielding evaluation (such as the 10% margin, point source approximation, and source adjacent to the interior cavity) and found that referencing dose rate calculations from the deformed impact limiter surface is conservative.

The staff found that the dose point locations meet the requirements in 10 CFR 71.47(a) and 71.51(a)(2).

5.3.2 Material Properties

The staff verified the material properties used in the shielding model are appropriate. The applicant used standard material compositions and densities for the shielding materials with the exception of tungsten, where tungsten is modeled as pure tungsten with a density lower than that used in the actual casks. Table 5-3 of the application lists the material properties the applicant used in their shielding model. The shielding models do not include the material within the impact limiter. The staff found this conservative and acceptable.

The applicant used a mixture of oxygen, nitrogen, and argon within the cavity. Inerting the cavity with argon is not a requirement of the package. However the staff found this assumption acceptable because the source was modeled adjacent to the cavity wall and therefore the contents of the cavity would not provide any gamma attenuation. In addition the low density of the air mixture does not provide significant attenuation.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant used the MCNP code, version 5, with continuous ENDF/B-VI photon cross sections to calculate the dose. This code and cross section set has been widely used in shielding evaluations and the staff found it acceptable for use in this application.

This code normalizes to a single source particle. The applicant scaled the data to account for the number of photons/decay and the activity limit of each nuclide. Through a sampling of the output files, the staff determined that this calculation was performed appropriately and found this acceptable.

To reduce run time for the MCNP code, the applicant used variance reduction techniques. The applicant employed importance splitting and source biasing. These techniques are described in Sections 5.4.1 of the application. The staff found the use of these techniques acceptable. The staff performed a calculation using the applicant's input deck and removed all biasing techniques. The staff ran this problem with sufficient histories to obtain results with low statistical error and found that the results are statistically equivalent to those with the variance reduction. The staff found that this further demonstrates that the applicant has appropriately implemented these techniques.

5.4.2 Input and Output Data

The applicant provided representative input and output files. The staff reviewed several of these files and determined that the information from the shielding models was appropriately input to the code.

5.4.3 Flux-to-Dose-Rate Conversion

The applicant stated that they used applicable codes and standards for the design, fabrication and testing of the shielding in the package as summarized in Table 2-8 of the application. The staff verified that the applicant also used established codes and standards in the shielding analyses. The applicant stated that they used the flux-to-dose-rate conversion factors from ANSI/ANS 6.1.1-1977. The staff verified that the conversion factors listed in representative MCNP input files are consistent with ANSI/ANS 6.1.1-1977. The staff found that the applicant meets the requirements of 10 CFR 71.31(c).

5.4.4 External Radiation Levels

The applicant calculated the external radiation levels at the deformed impact limiter surface and at 1 meter from this surface and 1 meter from the cask surface to account for HAC. The staff verified that the maximum calculated external radiation levels for all nuclides and packages in Tables 5-11, 5-12, 5-13, and 5-14 are within the allowable dose rates cited in 10 CFR 71.47(a). The applicant added an additional conservatism of 2σ and all calculated results show a margin of at least 10% to the regulatory limits. The staff verified that the selected analysis locations gave maximum dose rate results. The results of these calculations demonstrated that the AOS packages meet the dose rate limits in 10 CFR 71.47(a) and 10 CFR 71.51(a)(2).

5.5 Independent Calculations

The staff independently calculated the dose rates from the packages. For Co-60 and Cs-137 in the Model No. AOS-100A package, the staff used the MONACO/MAVRIC module which is part of the SCALE 6 code package. The staff used 200N-47G ENDF/B-VII.0 cross section library, and the 1977 ANS flux-to-dose-rate conversion factors. For other nuclide and package combinations the staff performed calculations using MICROSHIELD5. The results of the staff's calculations also show that the package meets the dose rate requirements in 10 CFR 71.47 and 10 CFR 71.51(a)(2).

5.6 References

"Radionuclide Transformations Energy and Intensity of Emissions," Annals of the ICRP, ICRP Publication 38, Volumes 11-13 1983

5.7 Evaluation Findings

The staff reviewed the description of the package design features related to shielding and the source terms and found them acceptable. The methods used are consistent with accepted industry practices and standards. The staff reviewed the maximum dose rates for NCT and HAC conditions and determined that the reported values were below the regulatory limit in 10 CFR 71.47 and 71.51.

Based on its review of the statements and representations provided in the application, the staff has reasonable assurance that the shielding evaluation is consistent with the appropriate codes and standards for shielding analyses and NRC guidance, and that the package design and contents satisfy the shielding and dose limits in 10 CFR Part 71.

6.0 CRITICALITY REVIEW

This Section is not applicable.

7.0 PACKAGE OPERATIONS

Chapter 7.0 of the application provides a description of package operations, including package loading and unloading operations, and preparation of an empty package for shipment.

7.1 Package Loading

Package loading operations include package preparation activities, radioactive materials loading, package closure, and preparation for transport.

Package preparation activities include (i) a review of the proposed contents' isotopic composition, quantities, decay heat, form, weight and geometry, (ii) the identification of the special form certificate if any, (iii) the identification of the shoring device to be used to ensure that its melting point is greater than 1000°F, and (iv) the identification of any additional shielding requirement. The package shall be visually inspected for damage and proper marking and labeling and radiation and contamination levels shall be checked for compliance with regulatory requirements. The package is then removed from the transport vehicle using appropriate rigging equipment and transferred to the loading area.

Package loading and closure activities include (i) the removal of the package lid and package lid plug for visual inspection of the cavity, (ii) the visual inspection of the lid sealing surfaces for damage or foreign material, (iii) the removal of the package's drain port, test port, vent port covers and pipe plugs, (iv) the installation of the lid guide pins for proper alignment of the lid with the lid attachment bolts and also for protection of the package lid metallic seal, (v) the placement of the contents into a rack, basket or shoring device, and their shoring within the package cavity, if needed, and (vi) the placement of the package lid plug, the installation of the lid of the package using the two lid guide pins installed in the lid threaded holes perpendicular to each other to maintain alignment of the lid attachment bolt holes with the package lid threaded holes.

Package preparation for transport activities include the proper torque of the package lid attachment bolt, the flushing of the cavity with dry air or nitrogen if the package was wet loaded, and the vacuum drying of the cavity until the cavity pressure is below or equal to 1 torr. Finally, a pipe thread sealant is put onto the plug thread areas and the drain port plugs, vent port plugs, and covers are installed. The package is then removed from the loading area, decontaminated, and radiation levels are measured for compliance with 10 CFR 71.87(i). A pre-shipment leak test must be performed to verify that the package containment system is properly assembled.

7.2 Package Unloading

Package unloading operations include the receipt of the package from the carrier, the removal of the lids and bolts, the unloading of the radioactive materials, and the release of the package for future transport operations.

Before unloading the contents of the package, a radiological and smear survey of the package surfaces must be done and the survey results are compared to the pre-shipment data survey. Once that all but five lid attachment bolts are removed, the package is transferred to the unloading area and the payload removed from the package using the detailed procedures developed for that facility.

After the removal of the contents, and further confirmation that the package cavity is completely empty, the lid of the package is lowered over the lid guide pins and onto the package before the package is moved to the site storage area.

7.3 Preparation of an Empty Packaging for Shipment

The cavity shall be visually inspected to verify that it is empty so that personnel can certify the package is "empty." A radiological survey of the cavity is performed to determine the extent of any contamination in accordance with site procedures, and the cavity decontaminated in accordance to 49 CFR 173.428. The cavity must also be dried if there is any free-standing water present.

The lid is then lowered on the package, the lid bolts are torqued in a criss-cross pattern to ensure even seal compression and the package inspected to ensure the drain port plugs, the vent port plugs, and covers are properly installed. The external surfaces of an empty package must be decontaminated to a level consistent with 49 CFR 173.428.

7.4 Evaluation Findings

To further ensure safe operation in maintaining containment integrity, the staff requested additional information on the detailed sealing installation and bolt torque procedures. The applicant revised the loading procedure to add adequate details about underwater seal installation procedure. Sealing surface will be inspected in the installation procedure to ensure perfect condition. The licensee also clarified that the bolt torque procedure would be performed above water, which eliminated the accuracy concern.

The staff reviewed the Operating Procedures in Chapter 7 of the application to verify that the package will be operated in a manner that is consistent with its design evaluation. On the basis of its evaluation, the staff concludes that the combination of the engineered safety features and the operating procedures provide adequate measures and reasonable assurance for safe operation of the proposed design basis fuel in accordance with 10 CFR Part 71.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Chapter 8 of the application identifies the inspections, acceptance tests and maintenance programs to be conducted on the package and verifies their compliance with the requirements of 10 CFR Part 71.

8.1 Acceptance Tests

Visual inspections of all component surfaces are conducted during packaging fabrication to identify overlaps, seams, cracks, and crevices. All welds are visually inspected and liquid-penetrant tested (root and final passes), and the package cavity is hydrostatically tested to verify that the containment boundary can support 1.5 times the design pressure.

The containment boundary is leak-tested before each use of the package. The lid metallic seal joint, the drain port, and the vent port are tested by connecting the test probe to the test port located between the seal's two seal rings and port cover areas and then determining the leak rate.

Materials and testing requirements are presented in Table Nos. 8-2 through 8-5 of the application. The application contains two sets of material properties for the FR-3700 foam materials. One set is presented in Tables 2-14 and 2-15 and the second set is presented in Appendix 2.12.5. Both of these sets were obtained from the foam manufacturer, General Plastics Manufacturing Co. The foam properties, shown in the tables, was taken from "DESIGN GUIDE FOR USE OF LAST-A-FOAM® FR-3700, FOR CRASH & FIRE PROTECTION OF RADIOACTIVE MATERIAL SHIPPING CONTAINERS," Rev. 05, and the properties in Appendix 2.12.5 were taken from an earlier revision of the same document. When AOS performed the applicable foam material analyses, the manufacturer's published property data was Revision 10/03, therefore the analyses used the specified data. When the new data was published in 2005, AOS assessed the difference in the data between the two revisions of the document and after consultation with the manufacturer, it was concluded not to revise the analytical work for the new values but rather address this issue at the time of manufacturing and to provide verification by the testing program imposed by the purchase order.

Staff noted that Table No. 8-5 of the application was not corrected from the previous revision of the application, and still reported the wrong densities of the foam. Since Chapter 8 of the application is referenced in the CoC, staff included a specific condition to measure the weight of the foam in each impact limiter and calculate its average density calculated based on the known volume of foam fill. The average density of the foam in each impact limiter must be within +/- 15% of 18 pcf, 8 pcf, and 11 pcf for the Model Nos. AOS-025, AOS-050, and AOS-100 packages, respectively.

As previously discussed, the analysis to determine the load in the cask structure of the package due to the "free drop" conditions, collapse analysis of the impact limiter, used the foam material properties given in Appendix 2.12.5 of the application. The load value resulting from this collapsed analysis represents the maximum load contribution of the foam material to be experienced by the cask structure due to the free drop event. To assure that this foam material limit is not exceeded due to the manufacturing process, AOS shall require in purchase documents, that the foam manufacturer, General Plastics Manufacturing Co., complete the series of tests specified in Table 8-5, "LAST-A-FOAM FR-3700 Series Foams – Testing Program," of the application. A series of tests must be performed for the foam formulation, each batch, and each pour to be able to identify any variations influencing the foam properties prior to the completion of the filling of the impact limiter. After the formulation test, AOS shall impose a hold point in the manufacturing process, to allow AOS to verify that the crush stress limit has been met by the foam. The average static crush value obtained from the test will be converted to a dynamic value and compared with values given in Appendix 2.12.5. If the values are equal or less than the Appendix 2.12.5 values, the manufacturing process will be allowed to continue to completion. If the values are greater, the foam material will be rejected and a new formulation established. The testing and validation of results are to be a part of the Quality Assurance documentation provided by General Plastics Manufacturing Co.

A thermal test is conducted for the first unit produced of each model, i.e., Model No. AOS-025, AOS-050, AOS-100A, AOS-100B, and AOS-100A-S.

8.2 Maintenance

Pre-shipment inspections are conducted prior to each shipment. Such inspections include visual checks and may also include the pressurization of the package cavity.

The closure seal and vent and drain threaded pipe plugs must be leak-checked annually or before the use of the package after a storage period of more than one year.

8.3 Evaluation findings

The first fabricated package shall undergo thermal testing to confirm its heat transfer capability. If the acceptance criteria specified in the application are not met, the package shall not be accepted until the root cause is determined, appropriate corrective actions are completed and the package is re-tested with acceptable results.

The staff reviewed the acceptance tests and maintenance programs for the AOS package and found them acceptable.

Based on the statements and representations in the application, the staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71.

CONDITIONS

The following conditions are included in the Certificate of Compliance:

(a) The package shall be prepared for shipment and operated in accordance with Chapter 7 of the application.

(b) The package must be tested and maintained in accordance with Chapter 8 of the application. In Table No. 8-5 of the application, the required nominal densities for formulating batches, and pouring test samples, shall be 18, 8, and 11 pcf for the Model Nos. AOS-25, AOS-50, and AOS-100 packages, respectively. Inspections noted in Section 8.2 of the application shall be performed at least once within the 12-month period prior to each use of the package.

(c) For transport by air, quantities are limited to the lesser of Table 1 of this certificate or 3,000 A_2.

(d) Prior to the first use of the package, and prior to each subsequent use, the package must be leak-tested to 10^{-7} std cm^3/sec.

(e) When contents are loaded under water, or if water is introduced in the cavity of the package, the package must be vacuum dried prior to shipment and the cavity of the package filled with helium for such shipments.

(f) The sealing surfaces of the package must be inspected and the seal replaced prior to each shipment.

(g) Appropriate shoring devices, to secure and immobilize inner containers, must be comprised of materials compatible with the radioactive contents and the cask cavity material. All shoring material within the cavity must have a melting point greater than 1,000°F.

(h) Torque values for the lid bolt and the connectors of the impact limiters must be as follows:

Model	Lid Bolt (ft-lb), lubricated	Impact limiter connector (ft-lb), lubricated
AOS-025A	35	18
AOS-050A	62.5	18
AOS-100A	500	70
AOS-100B	500	70
AOS-100A-S	500	70

(i) Fissile materials and irradiated fissile materials containing fission products are prohibited. No free-standing liquid is authorized. Any material with a melting point less than 1,000°F shall be in special form.

(j) The weight of the foam in each impact limiter must be measured and its average density calculated based on the known volume of foam fill. The average density of the foam in each impact limiter must be within +/- 15% of 18 pcf, 8 pcf, and 11 pcf for the Model Nos. AOS-025, AOS-050, and AOS-100 packages, respectively.

CONCLUSION

Based on the statements and representations contained in the application, and the conditions listed above, the staff concludes that the Model Nos. AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S packages have been adequately described and evaluated and that the packages meet the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9316, Revision No. 0,
on February 28, 2012.