AOS-FM9054
Rev. H-1, March 11, 2016
(Docket No. 71-9316)

Radioactive Material Transport Packaging System

Safety Analysis Report

for Model AOS-025, AOS-050, and AOS-100 Transport Packages

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Revision History

Revision	Date	Description of Changes
A	January 11, 2008	Preliminary release.
B	June 20, 2009	Preliminary release.
C	September 11, 2009	Preliminary release.
D	September 28, 2010	Preliminary release.
E	October 11, 2011	Preliminary release.
F	February 1, 2012	Initial Release.
G	July 27, 2012	Update to include cask lid elastomeric seal, and included text so the cask lid metallic seal is differentiated from the new elastomeric seal. Applied miscellaneous corrections (table of changes included with cover page of the submittal).
H	December 30, 2012	Updated in response to NRC RAIs. Applied miscellaneous corrections (table of changes included with cover page of the submittal).
H-1	March 11, 2016	Updated to add new isotope, Ir-194. General update to correct errors and incorporate changes communicated to NRC in letters dated April 4, May 14, and September 26, 2013, and May 6, June 5, and August 5, 2015. Applied miscellaneous updates and corrections (table of changes included with cover page of the submittal).

1 GENERAL INFORMATION

1.1 INTRODUCTION

This safety analysis report (SAR) is for a Type B(U)-96 non-fissile transport package, hereafter identified as a Radioactive Transport Packaging System, AOS Transport Packaging System, or transport package (in general). The transport package is configured in three (3) different sizes, identified as Models AOS-025, AOS-050, and AOS-100. These package models consist of three (3) main components – cask, impact limiter, and cask lid seal – as presented in Section . The transport packages will be used to transport Type B quantities of encapsulated solid materials or solid metals that meet *Normal* or *Special form* criteria. The authorized quantities of material to be transported is dependent upon the type of material being shipped and the associated decay heat load, or the radioactive shielding requirements, as appropriate, to provide containment and radiation shielding protection of the contents during Normal conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport, as required by *Title 10, Code of Federal Regulations, Part 71* (*10 CFR 71*) **[1.1]**. The AOS Transport Packaging System components are designed, fabricated, examined, and tested to the applicable requirements of the *ASME Boiler and Pressure Vessel (B&PV) Code* **[1.2]** (hereafter referred to as the "ASME Code"), as summarized in Subsection 2.1.4, "Identification of Codes and Standards for Package Design."

Methods and analysis for demonstrating compliance with the requirements of References **[1.1]** and **[1.2]** are present within this SAR. Chapter 2, "Structural Evaluation," documents compliance of the design and construction with the requirements of References **[1.1]** and **[1.2]**. Compliance is demonstrated by structural analyses and engineering evaluations for Normal and Hypothetical Accident conditions of transport requirements, and physical tests upon a prototype packaging, in accordance with *10 CFR 71.71* and *10 CFR 71.73* **[1.1]**. The mechanical properties for construction materials that affect the structural behavior of the transport packages are also included in Chapter 2.

In addition to the design criteria presented in Chapter 2, allowable stresses are evaluated for possible failure modes, including brittle fracture, fatigue, and buckling. Brittle fracture is not a consideration for the containment vessel, because the structural components are made of 300 series austenitic stainless steel, ASME/ASTM Type 304 or Type 316, including all components of the containment boundary. Austenitic stainless steels are not susceptible to brittle fracture at the minimum design and transport temperature, and their mechanical properties are relatively stable over the range of temperature required by regulations (References **[1.1]** and **[1.4]**).

The cask lid attachment bolts are fabricated from ASME SB-637, UNS N07718. This material is also excluded from brittle fracture consideration, in accordance with *ASME Code Section III, Division 1, paragraph NB-2311(a)(7)* in Reference **[1.2]**.

The structural analyses presented in Chapter 2 fully evaluates the mechanical requirements of the regulations (References **[1.1]** and **[1.4]**), and include the applied temperature effects generated by the thermal analyses. The evaluation results verify that the transport packages meet the performance requirements specified by *10 CFR 71* **[1.1]** and *IAEA TS-R-1* **[1.4]**.

Chapter 3, "Thermal Evaluation," documents the thermal evaluation required by the regulations, and verifies that the transport packages meet the performance requirements specified by References **[1.1]** and **[1.4]**.

Chapter 4, "Containment," documents the AOS Transport Packaging System's containment boundary and capabilities. The chapter also includes the cask lid attachment bolts analysis.

Chapter 5, "Shielding Evaluation," documents the radiation shielding evaluation for the transport package design.

Chapter 6, "Criticality Evaluation," is omitted from this SAR, because fissile materials and irradiated fissile materials containing fission products are not an authorized content for the AOS Transport Packaging System.

Chapter 7, "Package Operations," summarizes the instructions for the safe operation of all AOS Transport Packaging System models.

Chapter 8, "Acceptance Tests and Maintenance Program," presents the test program required by *10 CFR 71*, Subpart G **[1.1]**, to verify that the construction materials, fabrication processes, package design, and maintenance program requirements are fully addressed and satisfied at all times.

As previously noted, the AOS Transport Packaging System is available in three (3) model sizes – AOS-025, AOS-050, and AOS-100. The Model AOS-025 is scaled to 25% of the Model AOS-100, and the Model AOS-050 is scaled to 50% of the Model AOS-100. In addition to size, there are variations in shielding materials for the Model AOS-100, in which either tungsten alloy or carbon steel shielding is used. In the Model AOS-100, there is also a model that is double-ended (that is, the transport package opens on both ends). To distinguish the different models and their variations, the following designators are used throughout this SAR:

AOS-XXXY-Z

where:

XXX is the scale factor (25%, 50%, or 100%)

Y = A for tungsten alloy shielding (Models AOS-025A, AOS-050A, and AOS-100A) –or–

Y = B for carbon steel shielding (Model AOS-100B only)

Z = S to denote packages that have the double-ended opening configuration (Model AOS-100A-S only)

The transport packages are transported vertically, using a pallet design.

The difference between the Model AOS-100A and AOS-100B transport packages is the shielding material used. The difference between the Model AOS-100A and AOS-100A-S is the latter design has a double-ended opening configuration (that is, it can be loaded/unloaded from either end).

Figure 1-1 and Figure 1-2 provide isometric views of Models AOS-025A and AOS-050A, respectively. Figure 1-3 provides an isometric view of Models AOS-100A and AOS-100B. Figure 1-4 provides an isometric view of Model AOS-100A-S. Unless indicated otherwise throughout this SAR, all information related to the Model AOS-100A transport package is also applicable to the Model AOS-100B and AOS-100A-S transport packages.

The acceptance performance tests referenced in this SAR were conducted upon a prototype packaging, 165%-larger than the Model AOS-100, referred to herein, as the "AOS-165A prototype." Data pertaining to the AOS-165A prototype is used within this SAR solely for the evaluation of the Model AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S transport packages. This SAR does not request approval of the AOS-165A prototype.

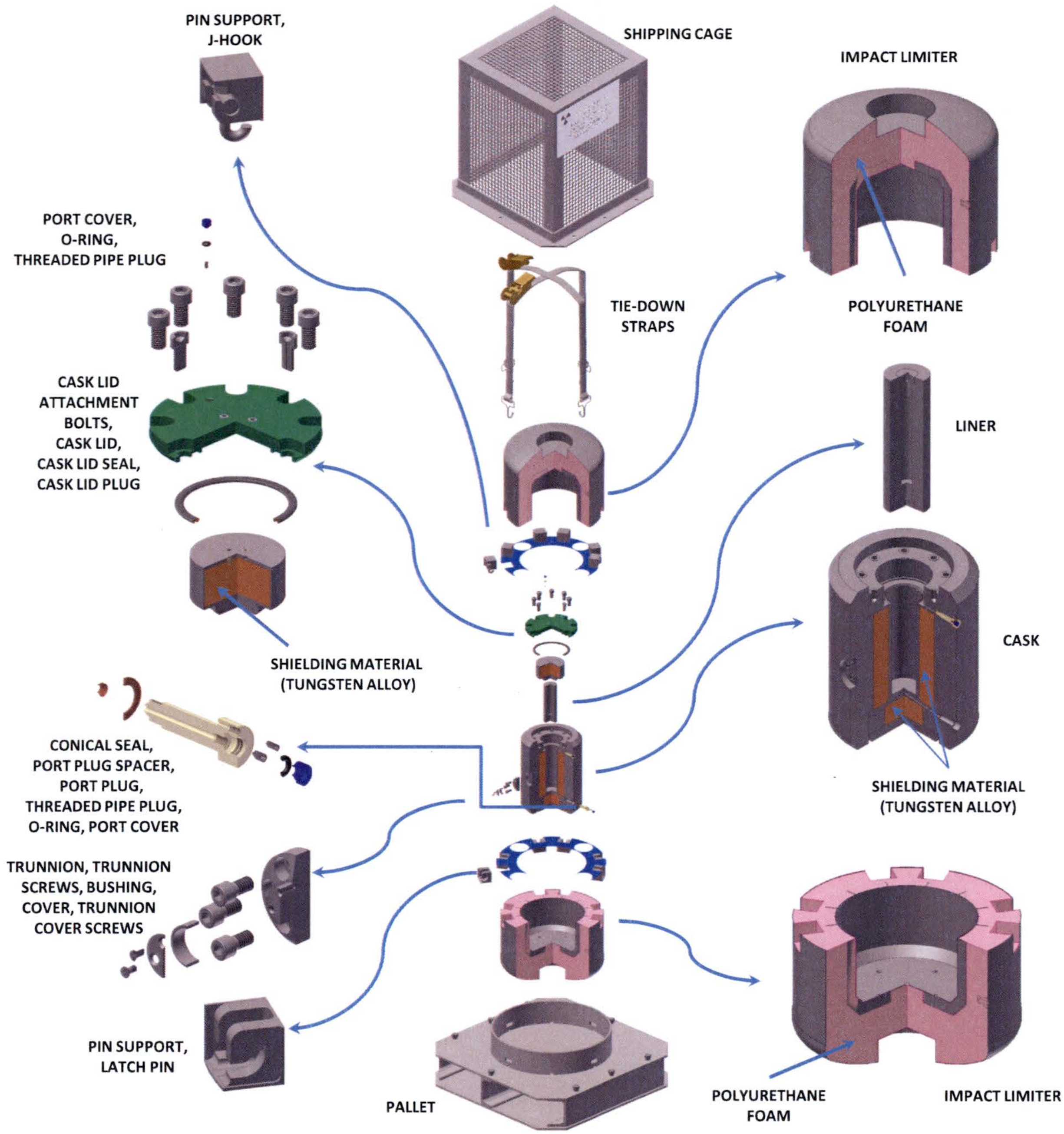

Figure 1-1. Isometric View – Model AOS-025A

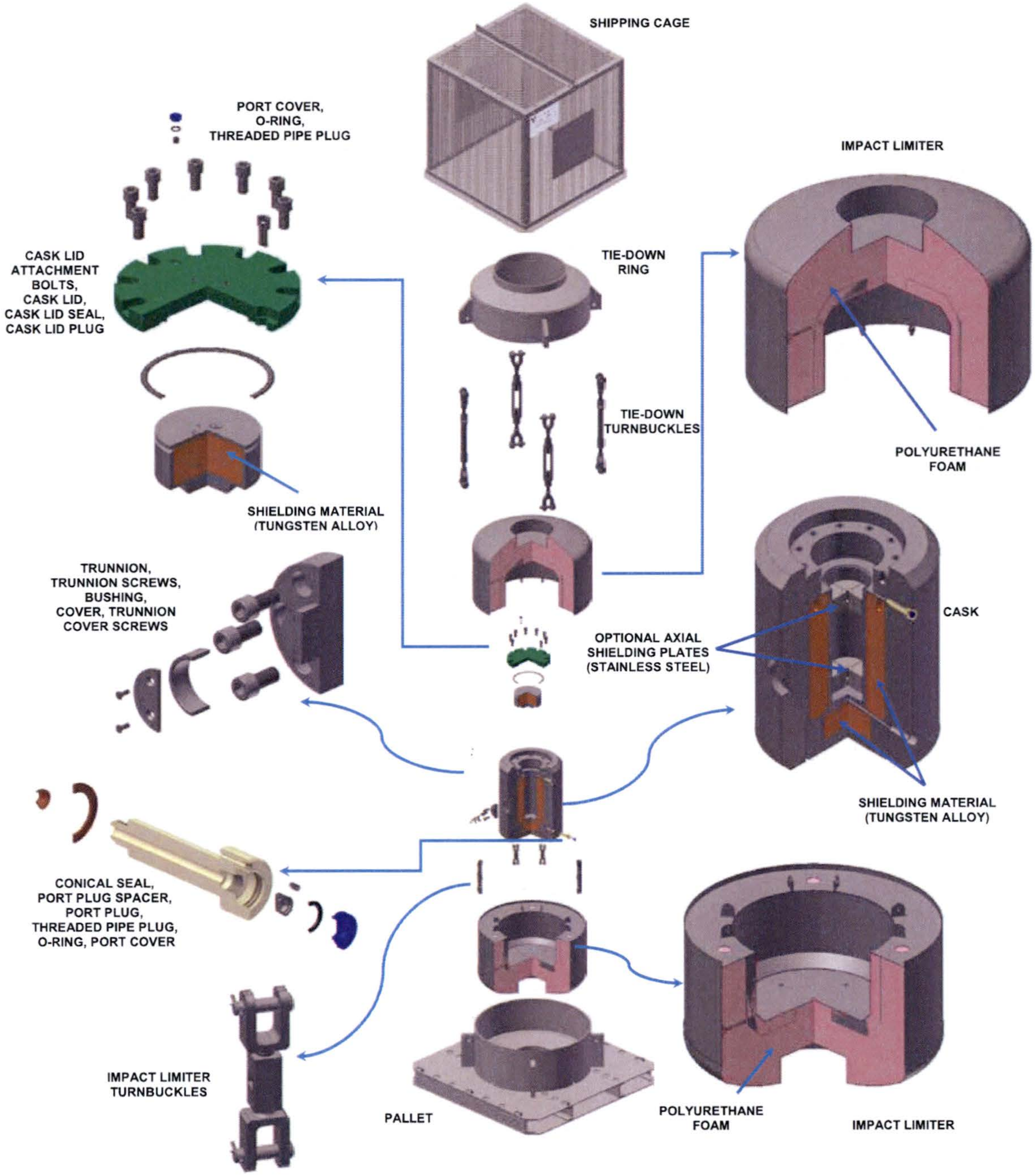

Figure 1-2. Isometric View – Model AOS-050A

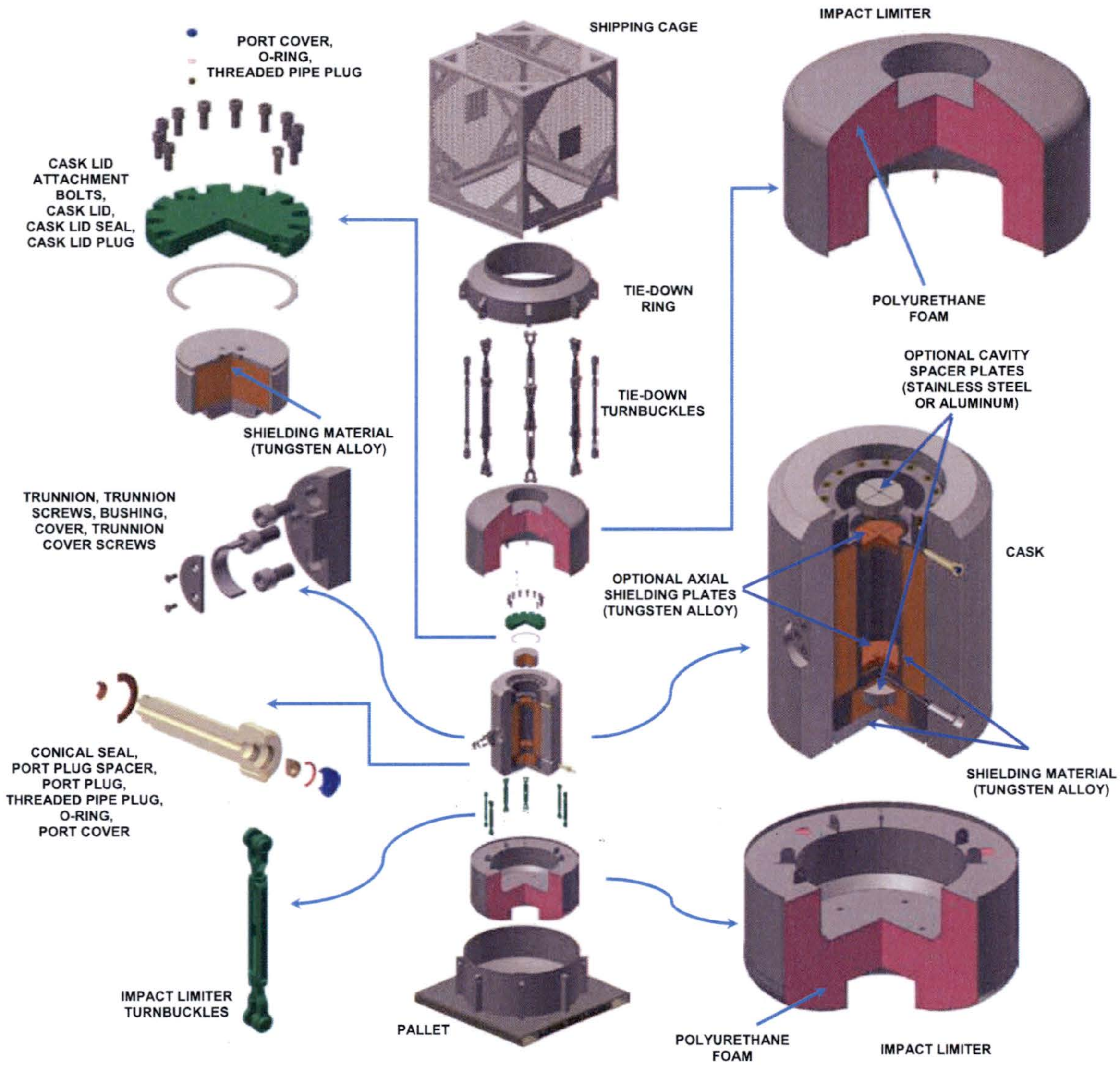

Figure 1-3. Isometric View – Models AOS-100A and AOS-100B

Note: *The Model AOS-100B is identical to the Model AOS-100A, with the exceptions that the Model AOS-100B uses carbon steel as its shielding material, and the optional axial shielding plates and cavity spacer plates are not permitted.*

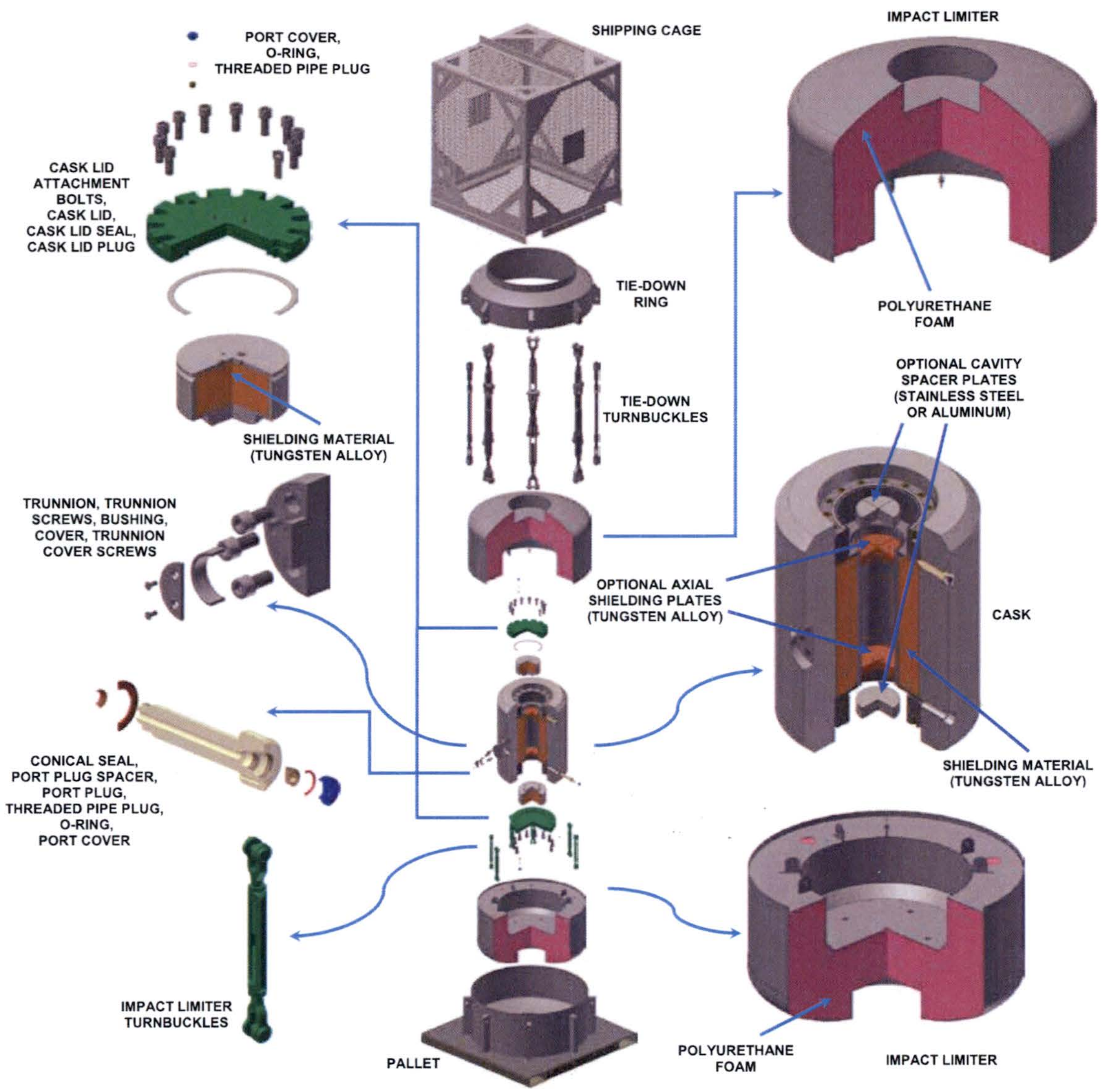

Figure 1-4. Isometric View – Model AOS-100A-S

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1.2 PACKAGE DESCRIPTION

The AOS Transport Packaging System designs are symmetric vertically, as well as axisymmetric. Table 1-1 summarizes the dimensions of each AOS Transport Packaging System model's maximum authorized packaging weight (including contents and impact limiters). The maximum weight of the contents, including all associated hardware and packing material, shall not exceed the values listed in Table 1-1.

Each transport package shall be weighed after fabrication, and that weight plus the maximum allowable content weight shall be compared against the maximum gross weight provided in the corresponding certificate drawing.

Table 1-1. AOS Transport Packaging System Dimensions and Maximum Authorized Package Weight – All Models

Model	Category	Dimensions, Basic (cm / in.)						Maximum Authorized Package Weight[a] (kg / lbs.)
		Packaging		Cask		Cavity		
		Width	Height	OD	Height	OD	Height	
AOS-025A	I	45.72	54.30	17.78	22.86	4.12	12.70	100
		18.00	21.38	7.00	9.00	1.62	5.00	220
AOS-050A	I	90.81	98.12[b]	35.56	45.72	8.26	25.40	681
		35.75	38.63[b]	14.00	18.00	3.25	10.00	1,500
AOS-100A	I	154.99	191.52[b]	71.12	91.44	16.51	50.80	5,675
		61.02	75.40[b]	28.00	36.00	6.50	20.00	12,500
AOS-100B	II	154.99	191.52[b]	71.12	91.44	16.51	50.80	4,994
		61.02	75.40[b]	28.00	36.00	6.50	20.00	11,000
AOS-100A-S	I	154.99	191.52[b]	71.12	91.44	16.51	50.80	5,675
		61.02	75.40[b]	28.00	36.00	6.50	20.00	12,500

a. The weights that comprise the maximum authorized package weight are defined in Table 2-7, "AOS Transport Packaging System Maximum Authorized Package Weight and Cg Locations – All Models."

b. The height specified includes the optional lifting bar on the shipping cage.

Additional cask assembly components are cask lid attachment bolts and port plugs, with threaded pipe plugs, O-Ring seals, and port plug covers.

Both the cask lid and bottom plate are located below the surface of the cask cavity shell, for protection during impact events.

Containment for the AOS Transport Packaging System (containment boundary) is provided within the cask component. The dashed lines in Figure 4-1, "Containment Boundary (Cask Lid Metallic Seal Shown)," illustrate the containment boundary, typical to all transport package models. There are two (2) penetrations into the cask cavity, located within the cask's top and bottom regions of the side surface. These cavity penetrations are used to drain and vent the cavity. A third penetration, located in the cask lid, is used for testing the seal's leak tightness. (For further details, refer to Chapter 4, "Containment.")

To augment the AOS Transport Packaging System's shielding characteristics, the AOS Transport Packaging System models may require the use of a liner, axial shielding plates, and/or cavity spacer plates, depending on the model, to convey certain quantities of radioactive materials. These liners, axial shielding plates, and cavity spacer plates are referenced in Table 1-5. To meet temperature regulation requirements, a shipping cage structure (refer to Paragraph 1.2.1.4) is used during package transport.

The AOS Transport Packaging System design does not require specific arrangement of the contents, other than those previously discussed, within the cavity. However, a basket or rack device can be used to shore the payload. These baskets or racks are typically made of aluminum or stainless steel material, and designed for the specific payload geometry.

1.2.1.2 Impact Limiter

The impact limiter is a major component consisting of a thin-walled cylindrical shell, with a dish head at one end and a flat disk at the other end. At the flat-disk end, there is a cylindrical recess, with an internal profile identical to that of the cask end profile. This cavity accommodates the cask in the transport configuration. Figure 2-5, "Isometric View – Typical Impact Limiter," presents an isometric view of the impact limiter.

Twelve (12) squared ribs are attached to the inside wall of the cylindrical recess section. Eight (8) of these ribs extend beyond the flat disk plate, which are used as turnbuckle attachment points. The turnbuckles are used to join the impact limiters and to partially enclose the cask component. For the Model AOS-025, the two (2) impact limiters entirely cover the cask, and the turnbuckles are replaced with "J" hooks.

The transport package exterior incorporates one (1) or more tamper-indicating devices, that are not readily breakable. While intact (that is, not broken), these devices provide evidence that the package has not been opened by unauthorized persons. (For further details regarding the tamper-indicating devices, refer to Chapter 7, "Package Operations.")

1.2.1.3 Cask Lid Seal

Two (2) types of cask lid seals are used. One consists of two (2) elastomeric O-Rings, a cross-section captured within one (1) or two (2) flat metal retainer rings to form a unit. The other is a metallic, double "C" cross-section arrangement.

The elastomeric seal is comprised of two (2) components:

- **O-Rings** – Silicone, Parker Compound S1224-70, ASTM D2000
- **Retainer Rings** – ASME SA-240/ ASTM A240, Type 304 or 316 Stainless Steel

The metallic seal is comprised of three (3) components:

- **Jacket** – Silver, ASTM B742
- **Spring** – Nickel-chromium alloy 90 UNS N07090
- **Lining** – SS304L UNS S30403 (may/may not be present)

The seal design provides a means for leak testing between the two (2) O-Rings (elastomeric seal) or double "C" cross-sections (metallic seal), by way of the cask lid's Test Port feature. (For further details regarding the cask lid seal, refer to Appendix 4.5.1, "Garlock Helicoflex Cask Lid Metallic Seal and AOS Cask Lid Elastomeric Seal Drawings.")

1.2.1.4 Other Components

In addition to the previously mentioned components, the AOS Transport Packaging System uses other components or structures, in support of its operations. A series of liners and shielding plates enhances the shielding characteristics for shipments of specific content. Refer to Table 1-2 and Table 1-2a for the requirements of when to use these shielding devices.

A transport pallet is used as a base for the transport packages, for tying down the package during transport.

The shipping cage is a five (5)-sided metal structure, with the pallet creating a sixth side, which completes a cube shape. Each side covered with an expandable metal mesh or screen material, that keeps unauthorized persons away from the transport package surfaces during transport, and provides a means to meet temperature regulation requirements.

The packages have no tie-down devices nor structural parts that can be used for unintended tie-down, thus satisfying the additional requirements of *10 CFR 71.45(b)* **[1.1]**.

1.2.2 Contents

Table 1-2 and Table 1-2a provide a list of the isotopes authorized for use with the AOS Transport Packaging System. Additionally, Table 1-2 and Table 1-2a demonstrate the use of curie content to meet the radioactive and thermal maximum limits specified in Table 1-3, for each transport package model. Furthermore, the shielding requirements specified in Table 1-2 and Table 1-2a apply, where applicable. The activity limits presented in Table 1-2a should be interpreted as follows: for a shipment with a total Ir-194 impurity up to the specified activity, the corresponding Ir-192 activity limit is listed (for example, for Model AOS-050A, any shipment with a total Ir-194 activity up to 10 Ci, the Ir-192 activity limit is 1,117 Ci).

The AOS Transport Packaging System can be used for transporting solid radioactive materials in *Normal* and *Special form*. Any materials with a melting point less than 538°C (1,000°F) are required to be in *Special form*. *Special form* materials require a current certificate of compliance. Dispersible *Normal form* materials are required to be enclosed within an inner container. An inner container is considered to be a "shoring device."

Fissile materials and irradiated fissile materials containing fission products are not authorized for this packaging. In addition, no free-standing liquid is permitted.

The package can be shipped by surface or air transport, and meets the requirements for non-exclusive transport. For air transport, quantities are limited to the lesser of Table 1-2, Table 1-2a, or 3,000 A_2.

All shoring materials used within the cask cavity must have a melting point greater than (i) 600°F for Co-60 in metallic form and Cs-137 in the form of cesium chloride and (ii) 900°F for all other contents

Radioactive contents can be in any location within the cask cavity, and unconstrained within the inner containers. Holders, fixtures, and packaging materials (shoring devices) must be used to secure the inner containers, so that the inner containers are immobilized. The containers must be comprised of materials that are compatible with the radioactive contents and cask cavity.

Radioactive contents are limited by the external radiation levels specified in *10 CFR 71.47* and *71.51* **[1.1]**, and *49 CFR 173.441* **[1.3]**. Exclusive-Use mode of shipment is required whenever the radiation dose rates of the package exceed the external radiation standards in *10 CFR 71.47(a)* **[1.1]** for non-exclusive use shipment.

There are no materials added to the package for the purpose of neutron absorption nor moderation. Radiation shields (that is, liners, axial shielding plates, and/or cavity spacer plates) are required in certain cases, as stipulated in Table 1-2 and Table 1-2a.

The construction materials of the AOS Transport Packaging System and their proposed contents are compatible with one another; no chemical nor galvanic reactions are expected to occur, including the generation of combustible gas.

The transport packages shall be loaded under ambient atmospheric pressure and temperature conditions. The containment boundary will not normally be pressurized; however, internal heating of the enclosed gases can increase the pressure.

The maximum gross weight of the AOS Transport Packaging System, including contents, is listed in Table 1-1.

The maximum decay heat, listed in Table 1-2 and Table 1-2a, is calculated using the constants presented in Chapter 5, "Shielding Evaluation."

Table 1-2. Activity Limits (All Isotopes Except Ir-192 and Ir-194)[a] – All Models

		Model							
		AOS-025		AOS-050		AOS-100			
	Decay Heat	A (10W)		A (100W)		A, A-S (400W)		B (400W)	
Isotope[b]	Ci/Watt[c]	TBq	Ci	TBq	Ci	TBq	Ci	TBq	Ci
Co-60	6.45E+01	4.92E-03	1.33E-01	2.78E-02	7.50E-01	1.01E+01	2.73E+02	4.03E-01	1.09E+01
Co-60-B	6.45E+01	–		–		3.05E+01	8.23E+02	–	
Co-60-C[d]	6.45E+01	–		–		7.48E+02	2.02E+04	–	
Cs-137	2.00E+02	3.70E-01	1.00E+01	7.13E-01	1.93E+01	1.32E+03	3.55E+04	2.15E+01	5.82E+02
Hf-181	2.31E+02	–		3.41E+00	9.23E+01	3.42E+03[e]	9.24E+04[e]	1.62E+02	4.39E+03
Zr/Nb-95[f]	6.17E+01	–		1.07E-01	2.90E+00	1.34E+02	3.61E+03	2.70E+00	7.31E+01
Ho-166	2.33E+02	4.87E-01	1.32E+01	2.81E+00	7.59E+01	–		–	
Yb-169	3.92E+02	1.45E+02[e]	3.92E+03[e]	3.49E+02	9.44E+03	–		–	
Shipping Configuration		Use of Liner 183C8485 is required		No additional shielding is required		**Co-60-B** quantities require use of Axial Shielding Plate 183C8491 **Co-60-C** quantities require use of Axial Shielding Plates 183C8491 and Cavity Spacer Plates 183C8518		No additional shielding is required	

a. Refer to Table 1-2a for Ir-192 and Ir-194 activity limits.

b. Solid material, including metals, that meets Normal or Special form criteria. Special form materials require a current certificate of compliance.

c. For detailed calculations of these values, refer to Appendix 5.5.1, "AOS Cask Isotopic Heat Load Calculations."

d. For Co-60-C quantities, the maximum allowable specific activity is 350 Ci/g (that is, no more than 350 Ci of Co-60 in a gram of Cobalt).

e. Activity limit based on cask decay heat limit.

f. Activity limits for parent/daughter mixed isotope systems apply to the parent isotope. An equilibrium concentration of the daughter is assumed in the evaluations provided in Chapter 5, "Shielding Evaluation," to provide limiting dose and heat responses for the AOS Transport Packaging System.

Table 1-2a. Ir-192 and Ir-194 Activity Limits – All Models

Model	Ir-192 Limit		Ir-194 Impurity		Decay Heat Ci/Watt[a]	Shipping Configuration
	TBq	Ci	TBq	Ci		
AOS-025A (10W)	2.62	71	0.0185	0.5	0.44	Use of Liner 183C8485 is required
	2.33	63	0.0740	2.0	0.40	
	2.10	57	0.1110	3.0	0.37	
AOS-050A (100W)	41.32	1,117	0.37	10	6.90	Use of Axial Shielding Plates 183C8519 is required
	39.84	1,077	0.74	20	6.71	
	36.88	997	1.48	40	6.33	
	33.92	917	2.22	60	5.94	
	30.96	837	2.96	80	5.56	
	28.04	758	3.70	100	5.18	
AOS-100A, AOS-100A-S (400W)	2,286.37	61,794	148.00	4,000	400.00	No additional shielding is required
	2,094.42	56,606	370.00	10,000	400.00	
AOS-100B (400W)	89.31	2,414	3.70	100	15.33	No additional shielding is required
	76.22	2,060	8.51	230	13.85	

a. *Ir-192 and Ir-194 generate 6.13E-03 W/Ci and 5.30E-03 W/Ci, respectively. (Refer to Table 5-22, "AOS Cask Isotopic Heat Load Results.")*

Table 1-3. Content Limitations – All Models

Model	Type	Content[a]	Decay Heat		Weight[b]	
			Watt	Btu/hr.	kg	lbs.
AOS-025A	Solid Material	*Normal Form* or *Special Form*	10	34.15	4.5	10
AOS-050A			100	341.5	27	60
AOS-100A			400	1,366	227	500
AOS-100B						
AOS-100A-S						

a. *Special form materials require a current certificate of compliance.*

b. *Maximum weight of contents including any additional shielding and shoring devices. Weight of contents can be adjusted so as not to exceed the maximum authorized gross weight of the package.*

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1.3 APPENDIX

1.3.1 AOS Transport Packaging System, Certification Drawings

Table 1-5 lists the certification drawings for the AOS Transport Packaging System's assembly, impact limiter, cask, liner, axial shielding plates, and cavity spacer plates, by model.

Table 1-5. AOS Transport Packaging System Certification Drawing List – All Models

	Drawing Part Number and Revision, by Model									
Component	**AOS-025A**	**Rev.**	**AOS-050A**	**Rev.**	**AOS-100A**	**Rev.**	**AOS-100B**	**Rev.**	**AOS-100A-S**	**Rev.**
Assembly	166D8142	I	105E9718	I	105E9711	I	105E9711	I	105E9711	I
Impact Limiter	105E9722	I	166D8138	I	105E9713	J	105E9713	J	105E9713	J
Cask[a]	166D8143	H	166D8137	H	105E9712G001	J	105E9712G002	J	105E9719	J
Liner	183C8485	H	–	–	–	–	–	–	–	–
Axial Shielding Plates	–	–	183C8519	A	183C8491	I	–	–	183C8491	I
Cavity Spacer Plates	–	–	–	–	183C8518	A	–	–	183C8518	A

a. *The G00x number appended to select drawing numbers represents a group within the drawing.*

AOS Drawing No. 183C8485

Model AOS-025A Liner

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Proprietary Information withheld from public disclosure per 10 CFR 2.390(a)(4).

AOS Drawing No. 183C8519

Model AOS-050A Axial Shielding Plates

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Proprietary Information withheld from public disclosure per 10 CFR 2.390(a)(4).

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AOS Drawing No. 183C8491

Model AOS-100A / AOS-100A-S Axial Shielding Plates

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Proprietary Information withheld from public disclosure per 10 CFR 2.390(a)(4).

AOS Drawing No. 183C8518

Model AOS-100A / AOS-100A-S Cavity Spacer Plates

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Proprietary Information withheld from public disclosure per 10 CFR 2.390(a)(4).

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2 STRUCTURAL EVALUATION

This chapter presents the structural evaluation of the AOS Transport Packaging System, and demonstrates that the design meets all applicable structure criteria. All components that comprise the AOS Transport Packaging System are evaluated to their regulatory requirements. Normal conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport are applied, in accordance with *10 CFR 71* and *IAEA TS-R-1* requirements (References **[2.1]** and **[2.2]**, respectively). Analyses comply with the methodology presented in *Regulatory Guide 7.6*, and loadings are combined, as provided in *Regulatory Guide 7.8* (References **[2.3]** and **[2.4]**, respectively).

- **Engineering Analyses** – Most of the engineering analyses are conducted using Finite Element Methods (FEM). The computer program applied in the analysis, LIBRA, is a multi-purpose finite element program applicable to static and dynamic analyses of linear and non-linear structural systems. A detailed description of the LIBRA program and a summary of the verification and qualification studies conducted in support of this evaluation are provided in Appendix 2.12.3.

  The Finite Element Analyses (FEA) are primarily concentrated on the cask structure, due to its containment functions. For the evaluated conditions, finite element analyses and appropriate material properties are used. For all drop conditions, the deceleration forces are determined using finite element methods. Load distributions are obtained for the Drop Test results. Results from the analyses demonstrate that all AOS Transport Packaging System models have the capability to meet regulatory requirements.

- **Free-Drop Test** – Free-Drop tests are conducted to verify the analytical procedure(s) used to determine cask impact accelerations, and forces within the impact limiter and cask structures for three (3) drop orientations. The drop tests also confirm the distribution of impact forces upon the cask structure.

- **Component Tests** – Component tests are conducted to enhance and/or verify understanding of materials and the behavior of AOS Transport Packaging System components under design conditions.

A summary of the engineering evaluation analyses conducted upon each AOS Transport Packaging System model is provided in Table 1-4, "AOS Transport Packaging System Analyses Summary – All Models."

2.5.2 Tie-Down Devices

The transport package contents and shield material are sealed within the cask. The cask is placed within the impact limiter, which is then placed upon the tie-down hardware. (Refer to Figure 1-1 through Figure 1-4 for an isometric view of each transport package model.)

10 CFR 71.45(b) **[2.1]** requires that, if there is a system of tie-down devices that is a structural part of the transport package, the system must be capable of withstanding a static force applied to the center of gravity of the package with the following:

1. Vertical component of two times the weight (2 W) of the package and its contents;
2. Horizontal component along the direction of travel of ten times the weight (10 W) of the package and its contents; and
3. Horizontal component in the transverse direction of five times the weight (5 W) of the package and its contents.

These applied loads do not generate stresses in any package material in excess of the yield strength of that material, as discussed in the following tables:

- Table 2-217, "Load Case 221, Forward 10g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S"
- Table 2-218, "Load Case 222, Lateral 5g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S"
- Table 2-219, "Load Case 223, Vertical 2g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S"

Detailed analyses of tie-down devices are presented in Appendix 2.12.12.

2.5.3 Other Devices

The following information demonstrates the analysis of other individual devices, and demonstrates conformance to or with *10 CFR 71.45(b)* **[2.1]**:

- Analyses of Shipping Cage and Shipping Cage Fasteners
    - Stress Analysis of Shipping Cages
    - Analysis of Shipping Cage Fasteners – Model AOS-025
    - Analysis of Shipping Cage Fasteners – Model AOS-050
    - Analysis of Shipping Cage Fasteners – Model AOS-100
- Analysis of Impact Limiter Mechanical Connectors
- Analyses of Shielding Devices
    - Stress Analysis of Axial Shielding Plate – Models AOS-100A and AOS-100A-S
    - Stress Analysis of Cavity Liner – Model AOS-025

2.5.3.3.2 Stress Analysis of Axial Shielding Plate – Models AOS-100A and AOS-100A-S

The Model AOS-100A/AOS-100A-S axial shielding plate is a 15.24-cm (6-in.)-diameter, 3.81-cm (1.5-in.)-thick annular, tungsten alloy disk. Both models use two (2) each, one upper and one lower, as illustrated in Figure 1-3, "Isometric View – Models AOS-100A and AOS-100B," and Figure 1-4, "Isometric View – Model AOS-100A-S." For both Normal conditions and Hypothetical Accident conditions of transport, the design load is a normal inertia loading. Under Normal conditions of transport, the plate is loaded by a 5 g inertia load. Under Hypothetical Accident conditions of transport, the plate is loaded by a 250 g inertia load.

The following data is used in the analysis:

Longitudinal Acceleration	A_z	=	250 g
Elastic Modulus	E	=	50.0×10^6 lb/in^2
Poisson's Ratio	ν	=	0.3
Yield Stress	F_y	=	75.0×10^3 lb/in^2
Density	ρ	=	0.655 lb/in^3

The axial shielding plate is analyzed by a LIBRA, axisymmetric analysis, using the model illustrated in Figure 2-23. The FEA model is composed entirely of Pian-Sumihara, mixed formulation, quad elements. The plate is assumed simply supported around the inside edge, and loaded with a 250 g inertia load in the negative Y direction.

Results of the FEA analysis are presented in Figure 2-23 and Figure 2-24. Figure 2-23 illustrates axial shielding plate vertical (Y) displacements, and Figure 2-24 illustrates axial shielding plate equivalent (Von Mises) stress. From Figure 2-23, it can be seen that under the 250 g inertia load, the maximum vertical displacement is 1.91×10^{-4} in. From Figure 2-24, it can be seen that under the 250 g inertia load, the maximum equivalent stress is 13.9 ksi:

$$MS = F_y / f_e - 1 = 75.0 / 13.9 - 1 = 4.4$$

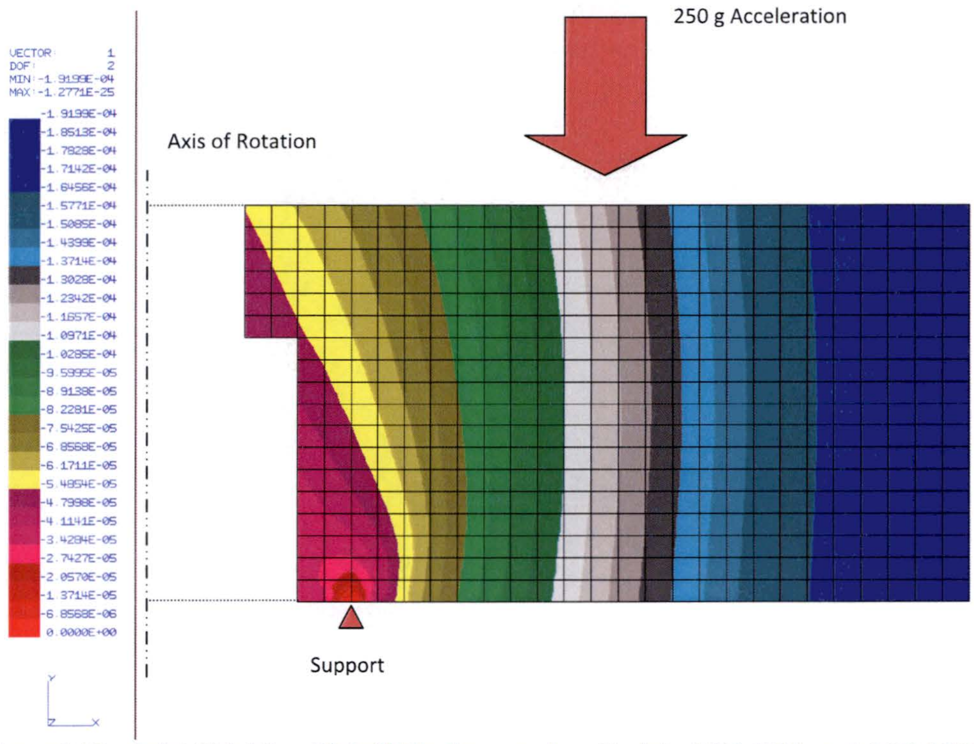

Figure 2-23. Axial Shielding Plate Y-Displacements – Models AOS-100A and AOS-100A-S

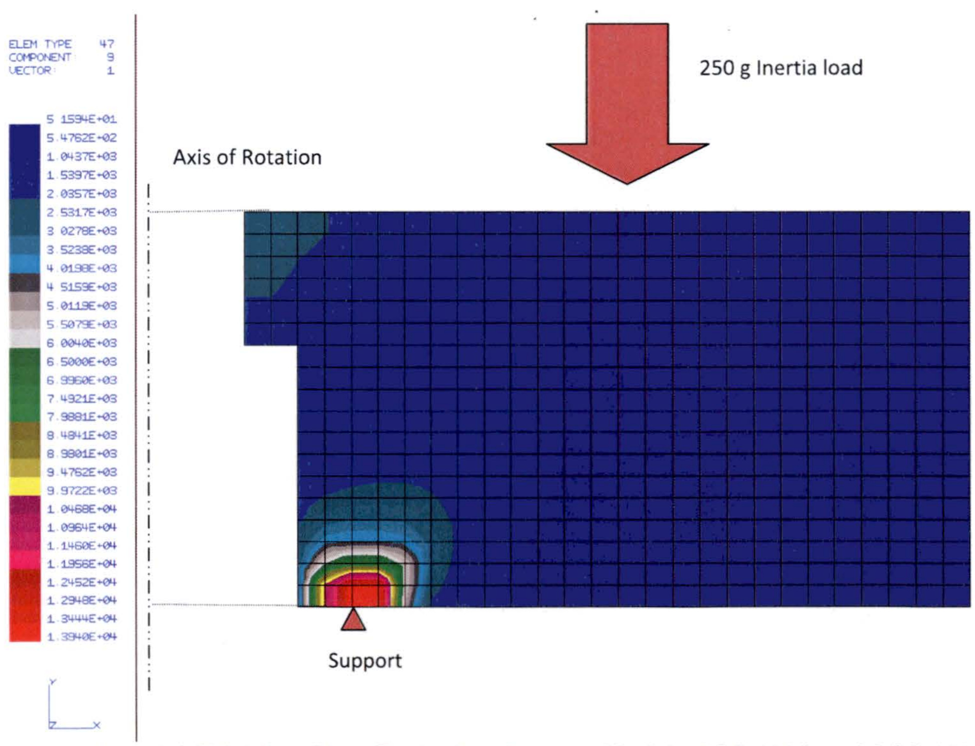

Figure 2-24. Axial Shielding Plate Equivalent Stress – Models AOS-100A and AOS-100A-S

2.12 APPENDIX

This appendix presents the following information:

- Data CDs
- Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100
  - Structural Evaluation Results – Model AOS-025A
  - Structural Evaluation Results – Model AOS-050A
  - Structural Evaluation Results – Models AOS-100A and AOS-100A-S
  - Structural Evaluation Results – Model AOS-100B
- LIBRA Finite Element Analysis Program and Verification Problems
- Description of LIBRA Files and Post-Processors: AOS Safety Analysis Report
- Selected Material Properties References
- Impact (Free-Drop) Test Report
  - Test Report: Drop Tests of the Alpha Omega Services Shipping Cask for Radioactive Material
  - Free-Drop Test Activity Record – Pre- and Post-Leak Test
- Dimensional Inspection Report
- Analysis of Content-Cask Lid Impact
- Comparison of Libra Static and Dynamic Impact Analysis
- Effect of Ribs on Stress at Foam-Cask Interface
- Analysis of 30-Ft. Drops with Shipping Cages
- Analysis of Tie-Down Devices
- Certificate of Conformance, General Plastics FR-3700 Series Foam – AOS-165A Prototype
- Analysis of Shipping Cage Lifting Bars – Models AOS-050A and AOS-100
- Shielding/Spacer Component Evaluation – Models AOS-050A, AOS-100A, and AOS-100A-S

2.12.14 Analysis of Shipping Cage Lifting Bars – Models AOS-050A and AOS-100

The optional Lifting Bar on the Model AOS-050A and AOS-100 transport packages are intended to lift only the Shipping Cage and **not** the entire package. As such, *10 CFR 71.45(a)* **[2.1]** requires that these features must be capable of being rendered inoperable for lifting the package during transport. For this purpose, the lifting holes on the Lifting Bar are covered prior to transport. Furthermore, the Lifting Bars are clearly marked with instructions to **not** lift the entire package.

The Shipping Cage on the Model AOS-025A transport package is easily lifted by hand and therefore is not fitted with a Lifting Bar.

The following analyses for the Model AOS-050A and AOS-100 transport packages demonstrate that the Lifting Bars can safely lift the Shipping Cages. A force of five (5) times the weight of the Shipping Cage is applied to the Lifting Bar and the stress and elastic stability are analyzed.

2.12.14.1 Analysis of Shipping Cage Lifting Bar – Model AOS-050A

The following information is presented:

- Description of the FEA model
- Stress Analysis
- Buckling Analysis

2.12.14.1.1 Description of FEA Model – Model AOS-050A

The FEA model of the Model AOS-050A Shipping Cage and Lifting Bar used in the analyses is illustrated in Figure 2-101 and Figure 2-102. Note that the FEA model used for the Model AOS-050A is not a scaled version of the model for the Model AOS-100. This is because there are significant differences between the two Shipping Cage designs and scaling was not possible.

The Model AOS-050A Shipping Cage consists of a welded aluminum frame and aluminum expanded-metal mesh faces fastened to the frame. The Shipping Cage frame is not reinforced at the corners by gusset plates as in the Model AOS-100 Shipping Cage. The Lifting Bar is a 0.25-in.-thick aluminum T-section beam with a 2-in.-wide base and 2-in. in height. The Lifting Bar is connected to the top of the cage frame with four ¼"-20 UNC bolts.

The FEA model contains 6922 nodes and 12432 elements, comprising 41532 degrees of freedom. The Shipping Cage frame and Lifting Bar are both modeled by STIF3 triangular shell elements. Connections between the lifting bar and frame are modeled by bolt (STIF56) and spring (STIF1) elements. The Lifting Bar is offset from the frame and connects to the frame by bolts and bearing points. The bolts connecting the Lifting Bar to the frame are modeled by STIF56 bolt elements, and bearing points are modeled by STIF1 spring elements. Due to the similarity of the Model AOS-050A and AOS-100 Shipping Cages, the locations of the spring elements modeling the bearing points are based on a gapped analysis performed on the Model AOS-100 Shipping Cage. (Refer to Paragraph 2.12.14.2.)

The expanded metal mesh is loosely attached to the Shipping Cage frame and provides little structural support while dominating structural response due to its flexibility, so it is not included in the analyses. To compensate for omission of the expanded metal mesh, the frame mass density is increased from 0.1 to 0.167 lb/in^3. The mass of the expanded metal mesh on the top surface is added to the frame midpoints as four (4) concentrated values.

The weight of the Model AOS-050A Shipping Cage is conservatively taken to be 41.9 lbs. Therefore, an inertial load of 5g results in a force of 209.5 lbs.

The Shipping Cage is assumed to be fixed at a single point at the center of the Lifting Bar, whereas in reality there are two (2) lifting points on the Lifting Bar. Using a single lifting point is a conservative assumption, because lifting by two (2) points away from the center of the Lifting Bar distributes the reaction forces and thereby reduces the stresses and deflection within the Lifting Bar.

In the FEA analysis, the vertical displacement was fixed only at the lifting point illustrated in Figure 2-101. To prevent rigid body motion in the stress analysis, a single node at the base of the Shipping Cage is fixed in the lateral directions. To prevent all possible rigid body modes in the stability analysis, four (4) nodes at the base of the cage and four (4) nodes at the top of the cage are fixed in the lateral directions.

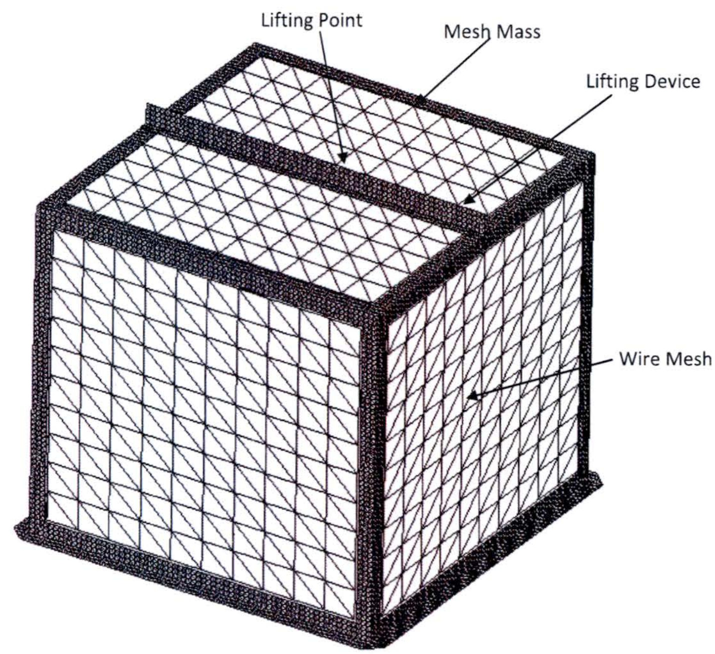

Figure 2-101. Shipping Cage and Lifting Bar – Model AOS-050A

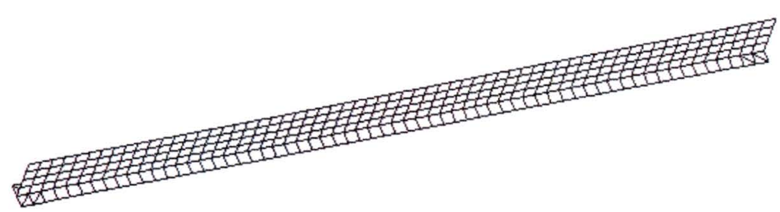

Figure 2-102. Lifting Bar – Model AOS-050A

2.12.14.1.2 Stress Results – Model AOS-050A

A LIBRA stress analysis (MAIN1) and an elastic stability analysis (MAIN11) were performed. The stress analysis results are presented in Table 2-346, Table 2-347, Figure 2-103, and Figure 2-104. Table 2-346 and Table 2-347 are maximum stress values generated by the LIBRA stress post-processor program STRPP.

Table 2-346 indicates that the maximum Equivalent stress in the Shipping Cage frame is 5.4 ksi. Table 2-347 indicates the maximum Equivalent stress in the Lifting Bar is 6.6 ksi.

Figure 2-103 illustrates the deformed geometry amplified by a factor of 25. Figure 2-104 illustrates the stress distribution in both the Shipping Cage and Lifting Bar.

The margins of safety are calculated as follows:

For ASME SB-209 Alloy 6061 T6, Yield Strength:	Fy	=	35.0 ksi
Shipping Cage Frame:	MS	=	Fy / f - 1 = 35.0 / 5.4 - 1 = 5.5
Lifting Bar:	MS	=	Fy / f - 1 = 35.0 / 6.6 - 1 = 4.3

The stresses within the bolts connecting the Lifting Bar to the Shipping Cage frame are listed in Table 2-348, and the associated contact forces are listed in Table 2-349. From Table 2-348, the maximum bolt equivalent stress indicated is 1,792 psi.

The margin of safety is calculated as follows:

Yield strength	=	20 ksi
MS	=	$\sigma_y / \sigma - 1 = 20 / 1.8 - 1 = 10.1$

Table 2-346. Maximum von Mises Stress in Shipping Cage Frame – Model AOS-050A

	Nx	Ny	Nxy	Mx	My	Mxy
1-6:	-8.0524E+02	4.2206E+02	-1.3235E+02	-1.8634E+01	-1.1487E+01	7.8909E+00
elem:	5071	4377	5137	5860	6359	5849
	S1	S2	T	Se		
7-10:	3.3567E+03	-5.6206E+03	2.5231E+03	5.3565E+03	(top)	
elem:	1377	6073	6073	6073		
11-14:	2.4308E+03	-4.2772E+03	2.0106E+03	4.1551E+03	(mid)	
elem:	2374	5071	5071	5071		
15-18:	4.1532E+03	-5.6220E+03	2.5236E+03	5.3577E+03	(bot)	
elem:	5860	5073	5073	5073		

Table 2-347. Maximum von Mises Stress in Lifting Bar – Model AOS-050A

	Nx	Ny	Nxy	Mx	My	Mxy
1-6:	2.5267E+02	1.6698E+03	1.9288E+02	-8.4826E+00	-7.3391E+00	2.7459E+00
elem:	26291	26295	26286	25011	25286	25021
	S1	S2	T	Se		
7-10:	6.7282E+03	-2.8792E+03	3.2548E+03	6.6216E+03	(top)	
elem:	26295	25286	26295	26295		
11-14:	6.7288E+03	-2.3575E+03	3.2550E+03	6.6222E+03	(mid)	
elem:	26295	26274	26295	26295		
15-18:	6.7295E+03	-2.3639E+03	3.2553E+03	6.6227E+03	(bot)	
elem:	26295	26274	26295	26295		

Table 2-348. Bolt Stresses – Model AOS-050A

ELEM	Px	Py	Pz	SIGMA	TAU	EQV_STR
27002	6.500E+01	-2.952E+01	1.426E+01	1.324E+03	6.679E+02	1.758E+03
27001	6.498E+01	2.971E+01	1.697E+01	1.324E+03	6.970E+02	1.792E+03
27012	6.498E+01	-2.958E+01	-1.481E+01	1.324E+03	6.739E+02	1.765E+03
27011	6.499E+01	2.974E+01	-1.643E+01	1.324E+03	6.921E+02	1.786E+03

Table 2-349. Contact Forces – Model AOS-050A

ELEMENT:	27022	P =-1.14484E+01	U =-1.14484E-02
ELEMENT:	27021	P =-1.14510E+01	U =-1.14510E-02
ELEMENT:	27032	P =-1.14498E+01	U =-1.14498E-02
ELEMENT:	27031	P =-1.14466E+01	U =-1.14466E-02

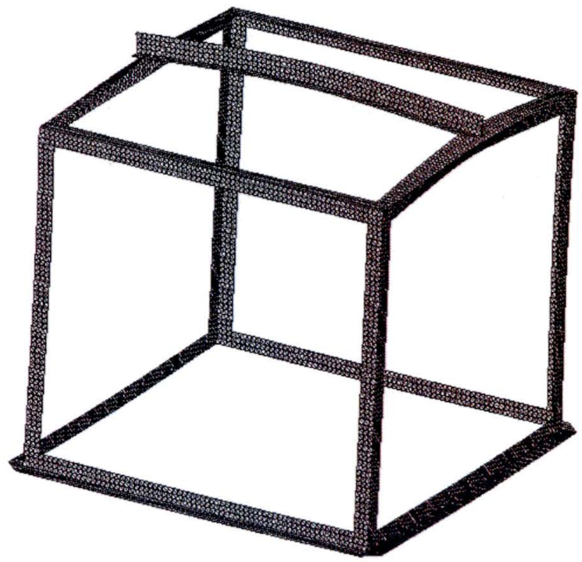

Figure 2-103. Deformation of Frame and Lifting Bar under Inertia Loading – Model AOS-050A

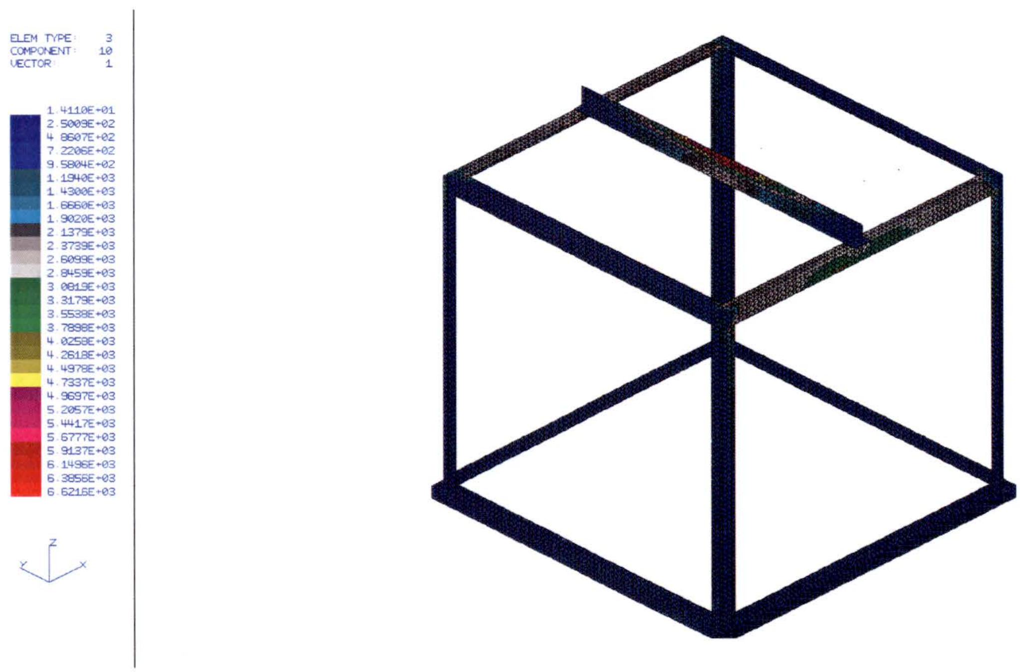

Figure 2-104. Equivalent Stress within Shipping Cage Frame and Lifting Bar – Model AOS-050A

2.12.14.1.3 Buckling Analysis – Model AOS-050A

A LIBRA elastic stability analysis (MAIN11) was performed on the Model AOS-050A Shipping Cage and Lifting Bar, using the FEA model illustrated in Figure 2-101 (expanded metal mesh excluded). A LIBRA elastic stability analysis produces an eigenvalue that corresponds to the load factors at buckling. The solution is iterative and convergence to the lowest buckling mode is listed in Table 2-350. The buckling mode is illustrated in Figure 2-105, with only the Lifting Bar shown for clarity. Table 2-350 indicates that the lowest buckling load is -20.5 times the applied inertia load. The negative eigenvalue in Table 2-350 indicates that the buckling mode corresponds to an inertia load in the upward or +Z direction, and the mode for a downward inertia load would have a load factor greater than 20.5.

The LIBRA Input Files used for the Model AOS-050A Lifting Bar analysis are as follows:

- AOS-050-CAGE-LIFT — Principal file
- AOS-050-CAGE-LIFT-A — Mesh connections generated by the PRODATA pre-processing data program

Table 2-350. Convergence of Elastic Stability Analysis, Mode 1 – Model AOS-050A

ITERATION	CONVERGENCE	EIGENVALUE
1	1.00000E+00	8.49558E+02
2	1.00598E+01	7.68153E+01
3	9.23549E-02	8.46314E+01
4	8.36717E-01	5.18313E+02
5	4.87923E+00	-8.81600E+01
6	1.12753E+00	-4.14377E+01
7	4.09124E-01	-2.94067E+01
8	1.90801E-01	-2.46949E+01
9	9.47090E-02	-2.25584E+01
10	4.79963E-02	-2.15253E+01
11	2.45209E-02	-2.10101E+01
12	1.25717E-02	-2.07493E+01
13	6.45601E-03	-2.06162E+01
14	3.31806E-03	-2.05480E+01
15	1.70601E-03	-2.05130E+01
16	8.77339E-04	-2.04950E+01
17	4.51232E-04	-2.04858E+01
18	2.32090E-04	-2.04810E+01
19	1.19378E-04	-2.04786E+01
20	6.14044E-05	-2.04773E+01
21	3.15848E-05	-2.04767E+01
22	1.62464E-05	-2.04763E+01
23	8.35679E-06	-2.04761E+01

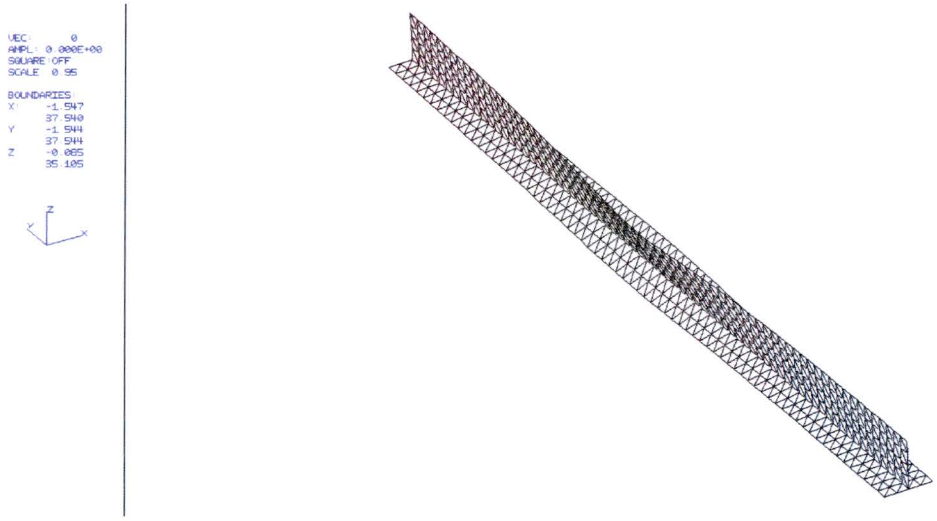

Figure 2-105. Lifting Bar First Buckling Mode – Model AOS-050A

2.12.14.2 Analysis of Shipping Cage Lifting Bar – Model AOS-100

The following information is presented:

- Description of the FEA model
- Stress Analysis
- Buckling Analysis

2.12.14.2.1 Description of FEA Model – Model AOS-100

This analysis is based largely on application of the LIBRA FEA program. The FEA models of the Shipping Cages and Lifting Bars used in the analyses are illustrated in Figure 2-106 and Figure 2-107.

The Model AOS-100 Shipping Cage structure consists of an aluminum frame reinforced at the corners by gusset plates, and stainless steel expanded-metal mesh faces. The Lifting Bar is a 0.375-in.-thick aluminum T-section beam with a 4-in.-wide base and 4 in. in height. The base of the T-section Lifting Bar in the FEA model was reduced to 2-in. wide. This makes the analysis results more conservative.

The Lifting Bar is connected to the top of the Shipping Cage frame with four ½"-13 UNC bolts.

The wire mesh is loosely attached to the Shipping Cage frame and provides little structural support while dominating structural response due to its flexibility, so it is not included in the analyses. To compensate for omission of the expanded metal mesh, a 6g inertia load is applied to the frame and considered to be an effective 5g loading. The weight of the Model AOS-100 Shipping Cage is conservatively taken to be 410 lbs. Therefore, an inertial load of 5g results in a force of 2,050 lbs.

The weight of the Shipping Cage without the expanded-metal mesh was taken to be 342.5 lbs. In the analysis, the applied load is six (6) times this weight or 2,055 lbs.

The cage is assumed to be fixed at a single point at the center of the Lifting Bar, whereas in reality there are two (2) lifting points on the Lifting Bar. Using a single lifting point is a conservative assumption, because lifting by two (2) points away from the center of the Lifting Bar distributes the reaction forces and thereby reduces the stresses and deflection within the Lifting Bar.

In the FEA analysis, the vertical displacement was fixed only at the Lifting Point illustrated in Figure 2-106, and lateral displacements were fixed at four (4) points on the base of the Shipping Cage to prevent rigid body motion.

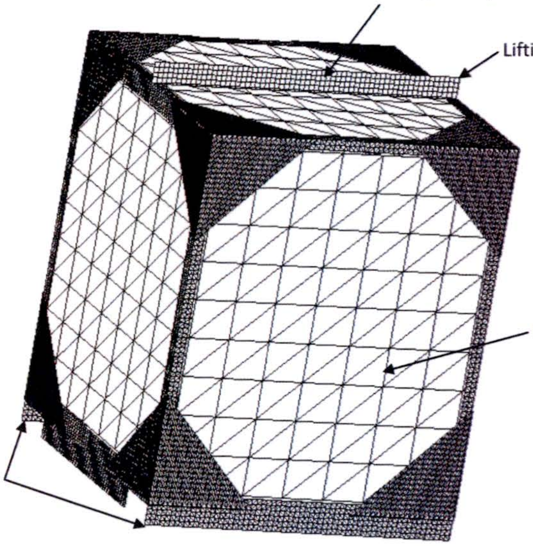

Figure 2-106. Shipping Cage and Lifting Bar – Model AOS-100

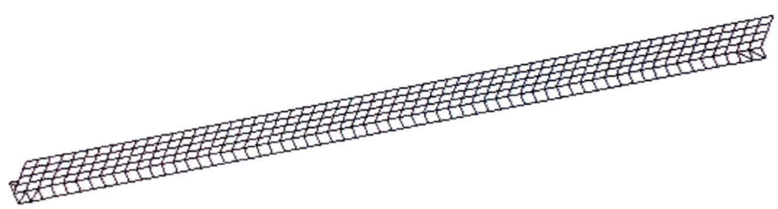

Figure 2-107. Lifting Bar – Model AOS-100

The bolted connections between the Lifting Bar and the Shipping Cage frame are analyzed using a LIBRA nonlinear analysis (MAIN2). The bolted connections transfer inertia load by a combination of bolt tension and bearing forces. A section of the cage model showing one (1) of the two (2) bolted connections is provided in Figure 2-108. Under inertia load, the Lifting Bar and frame deform (refer to Figure 2-112). As a result of this deformation, the Lifting Bar bears on the frame. The bearing points and bolt forces are determined by a LIBRA MAIN2 nonlinear analysis, in which possible bearing points are modeled by gap elements. The potential gap elements are located along lines labeled Contact Line 1 and Contact Line 2 in Figure 2-108. The MAIN2 solution process is iterative and in each iteration, the contact elements are assigned opened or closed status depending on the sense of the element force. The solution is considered converged when there is essentially no change in displacements, which indicates no change in element forces.

In the FEA model, there are 12 gapped elements numbered 75001 to 75012, representing potential contact points, and four (4) bolt elements numbered 75101 to 75104, representing the bolts.

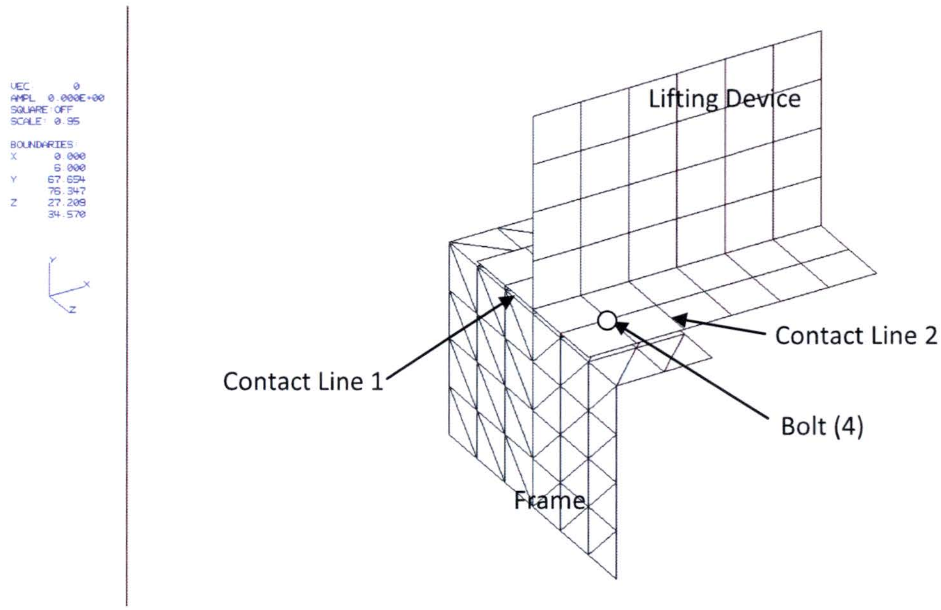

Figure 2-108. Model of Lifting Bar Bolted Connection – Model AOS-100

2.12.14.2.2 Stress Results – Model AOS-100

The Shipping Cage and Lifting Bar stress analysis results are presented in Table 2-351, Table 2-352, Figure 2-109, Figure 2-110, and Figure 2-111. Table 2-351 and Table 2-352 list the maximum stress values generated by the LIBRA stress post-processor program (STRPP). From Table 2-351, the maximum von Mises or Equivalent stress indicated within the Shipping Cage frame is 5.3 ksi. From Table 2-352, the maximum von Mises stress indicated within the Lifting Bar is 14.4 ksi. Figure 2-109 illustrates the vertical displacements. Figure 2-110 and Figure 2-111 illustrate the stress distributions within the Shipping Cage frame and Lifting Bar, respectively. The margins of safety are calculated as follows:

For ASME SB-209 Alloy 6061 T6, Yield Strength:	Fy	=	35.0 ksi
Shipping Cage Frame:	MS	=	Fy / f - 1 = 35.0 / 5.3 - 1 = 5.6
Lifting Bar:	MS	=	Fy / f - 1 = 35.0 / 14.4 - 1 = 1.4

For the bolting analysis, the resulting contact and bolt element forces and displacements are listed in Table 2-353 and Table 2-354, respectively. Data in these tables is taken directly from the LIBRA stress post-processor program (STRSPP). In Table 2-353, the elements with positive displacements correspond to open gaps and have null forces, and the elements with negative displacements correspond to closed gaps and have compressive forces. Closed gap elements are all located on Contact Line 2 in Figure 2-108, indicating that the inner edge of the Shipping Cage frame bears against the Lifting Bar.

From Table 2-354, the maximum force indicated within the bolt elements is 765 lbs. and the average force indicated is 743 lbs. The average bolt force without prying action is approximately the total inertia force divided by the quantity of bolts. There are four (4) bolts and the total inertia force is 2,055 lbs. Therefore, the average bolt force without prying is approximately 514 lbs. Thus, prying action increases bolt forces by about 50%.

Table 2-351. Maximum von Mises Stress in Shipping Cage Frame – Model AOS-100

	Nx	Ny	Nxy	Mx	My	Mxy
1-6:	-2.5387E+03	3.8960E+02	-3.4725E+02	-5.5458E+01	-3.5749E+01	1.6591E+01
elem:	19048	22361	18859	25815	25815	25809
	S1	S2	T	Se		
7-10:	4.0849E+03	-5.5433E+03	2.5484E+03	5.3341E+03	(top)	
elem:	15812	26048	26048	26048		
11-14:	3.7742E+03	-5.0820E+03	2.3585E+03	4.9097E+03	(mid)	
elem:	15812	19048	26048	19048		
15-18:	4.0846E+03	-5.5433E+03	2.5484E+03	5.3341E+03	(bot)	
elem:	19312	19048	19048	19048		

Table 2-352. Maximum von Mises Stress in Lifting Bar – Model AOS-100

	Nx	Ny	Nxy	Mx	My	Mxy
1-6:	-4.5158E+03	1.4469E+03	-1.3295E+03	-2.6969E+01	-2.1294E+01	-9.9870E+00
elem:	70187	70186	70248	70532	70623	17221
	S1	S2	T	Se		
7-10:	8.6655E+03	-1.2899E+04	7.7629E+03	1.4393E+04	(top)	
elem:	70218	70187	70187	70187		
11-14:	8.6655E+03	-1.2899E+04	7.7629E+03	1.4393E+04	(mid)	
elem:	70218	70187	70248	70248		
15-18:	8.6655E+03	-1.2899E+04	7.7629E+03	1.4393E+04	(bot)	
elem:	70218	70248	70248	70248		

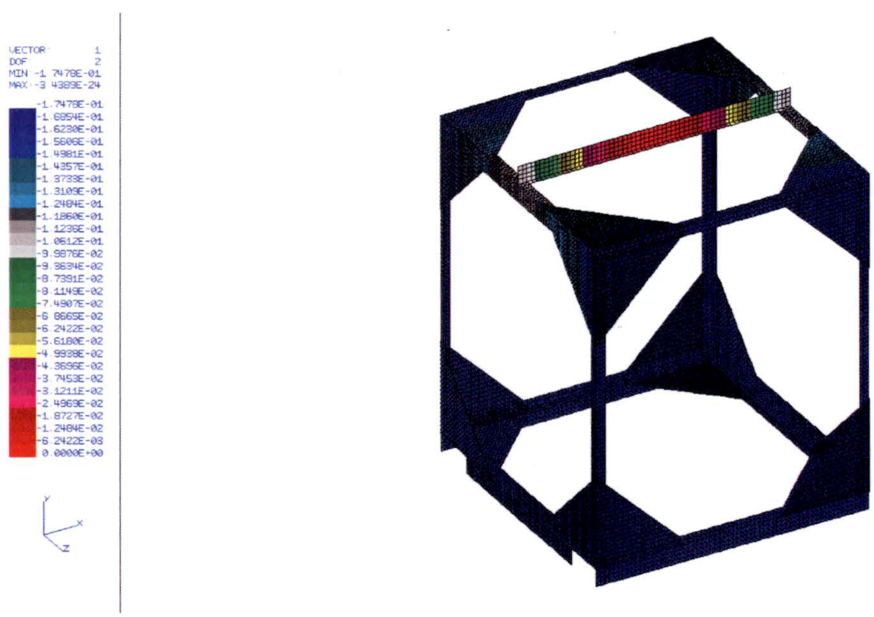

Figure 2-109. Shipping Cage Vertical Displacements – Model AOS-100

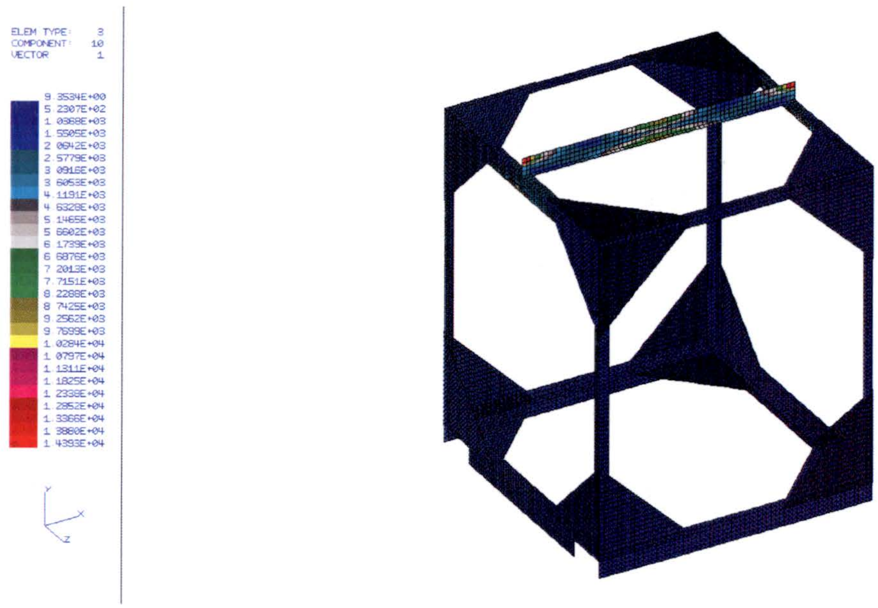

Figure 2-110. Shipping Cage von Mises Equivalent Stress – Model AOS-100

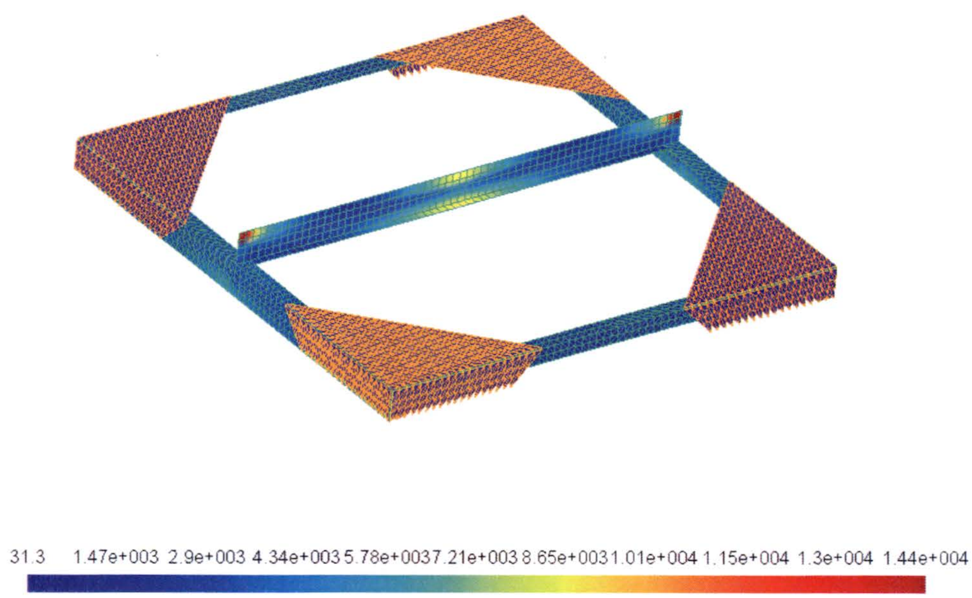

Figure 2-111. Lifting Bar von Mises Equivalent Stress – Model AOS-100

For a maximum force within the bolts of 765 lbs., the bolt stress is calculated as follows.

Bolt diameter	=	0.5 in.
Stress area	=	0.142 in^2
Stress	=	765 lbs. / 0.142 in^2 = 5,387 psi

The margin of safety is calculated as follows:

Yield strength	=	20 ksi
MS	=	$\sigma_y / \sigma - 1 = 20 / 5.4 - 1 = 2.7$

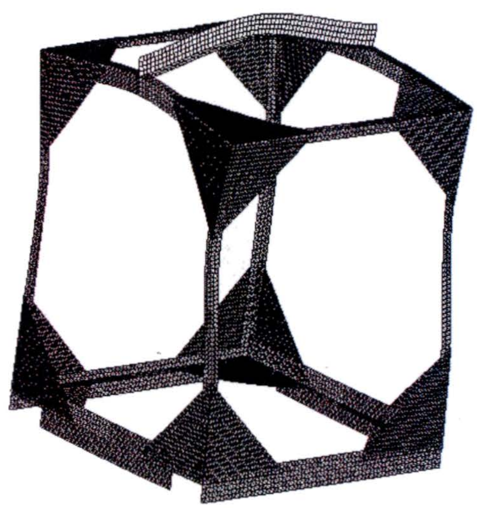

Figure 2-112. Deformation of Frame and Lifting Bar Under Inertia Loading – Model AOS-100

Table 2-353. Displacements and Forces within Contact Elements – Model AOS-100

ELEMENT	FORCE (lb)	DISPLACEMENT (in)
75001	0.00000E+00	3.34722E-03
75002	0.00000E+00	5.01011E-03
75003	0.00000E+00	3.34722E-03
75004	-2.61472E+02	-2.61472E-04
75005	0.00000E+00	1.22887E-04
75006	-2.61472E+02	-2.61472E-04
75007	0.00000E+00	3.51343E-03
75008	0.00000E+00	5.26376E-03
75009	0.00000E+00	3.51343E-03
75010	-2.74541E+02	-2.74541E-04
75011	0.00000E+00	1.43012E-04
75012	-2.74542E+02	-2.74542E-04

Table 2-354. Displacements and Forces within Bolt Elements – Model AOS-100

ELEMENT	FORCE (lb)	DISPLACEMENT (in)
75101	7.20829E+02	7.20829E-04
75102	7.20829E+02	7.20829E-04
75103	7.65040E+02	7.65040E-04
75104	7.65040E+02	7.65040E-04

2.12.14.2.3 Buckling Analysis – Model AOS-100

A LIBRA elastic stability analysis (MAIN11) was performed on the Shipping Cage and Lifting Bar, using the FEA model illustrated in Figure 2-106 (expanded metal mesh excluded). A LIBRA elastic stability analysis produces an eigenvalue that corresponds to the load factor at buckling. The solution is iterative, and convergence is listed in Table 2-355 and Table 2-356 for Buckling Modes 1 and 2, respectively. The first buckling mode's shapes are illustrated in Figure 2-113 and Figure 2-114, with only the Lifting Bar shown for clarity. The second buckling mode is obtained by fixing the Lifting Bar laterally at the load point, thereby preventing the first mode. Table 2-355 indicates that the lowest buckling load is -4.5 times the applied inertia load; however, the negative sign indicates that the mode corresponds to a load in the opposite direction of the applied load. Because the inertia load is not reversible, the second mode is the buckling mode, and from Table 2-356 indicates that the buckling load factor is 6.94.

The LIBRA Input Files used for the Model AOS-100 Lifting Bar buckling analysis are as follows:

- AOS-100-CAGE-LIFT — Principal file
- AOS-100-CAGE-LIFT-A — Mesh connections generated by the PRODATA pre-processing data program
- AOS-100-CAGE-LIFT-1 — Principal file for MAIN2 bolting analysis

Table 2-355. Convergence of Elastic Stability Analysis, Mode 1 – Model AOS-100

ITERATION	CONVERGENCE	EIGENVALUE
1	1.00000E+00	5.82771E+01
2	2.00942E-01	-4.85262E+01
3	4.62168E+00	-8.63197E+00
4	5.25698E-01	-5.65772E+00
5	1.59189E-01	-4.88075E+00
6	5.61581E-02	-4.62123E+00
7	2.13370E-02	-4.52469E+00
8	8.51010E-03	-4.48651E+00
9	3.50804E-03	-4.47082E+00
10	1.47828E-03	-4.46422E+00
11	6.31961E-04	-4.46141E+00
12	2.72663E-04	-4.46019E+00
13	1.18333E-04	-4.45966E+00
14	5.15454E-05	-4.45943E+00
15	2.25056E-05	-4.45933E+00
16	9.84083E-06	-4.45929E+00

Table 2-356. Convergence of Elastic Stability Analysis, Mode 2 – Model AOS-100

ITERATION	CONVERGENCE	EIGENVALUE
1	1.00000E+00	5.82310E+01
2	3.62437E+00	1.25922E+01
3	3.99519E-01	8.99752E+00
4	8.25793E-02	8.31118E+00
5	5.20557E-02	7.89995E+00
6	4.07590E-02	7.59056E+00
7	3.08370E-02	7.36350E+00
8	2.17598E-02	7.20668E+00
9	1.44360E-02	7.10412E+00
10	9.15569E-03	7.03967E+00
11	5.63609E-03	7.00022E+00
12	3.40524E-03	6.97646E+00
13	2.03429E-03	6.96230E+00
14	1.20722E-03	6.95390E+00
15	7.13661E-04	6.94894E+00
16	4.20968E-04	6.94602E+00
17	2.48016E-04	6.94430E+00
18	1.46024E-04	6.94328E+00
19	8.59441E-05	6.94269E+00
20	5.05748E-05	6.94234E+00
21	2.97589E-05	6.94213E+00
22	1.75101E-05	6.94201E+00
23	1.03029E-05	6.94194E+00
24	6.06220E-06	6.94189E+00

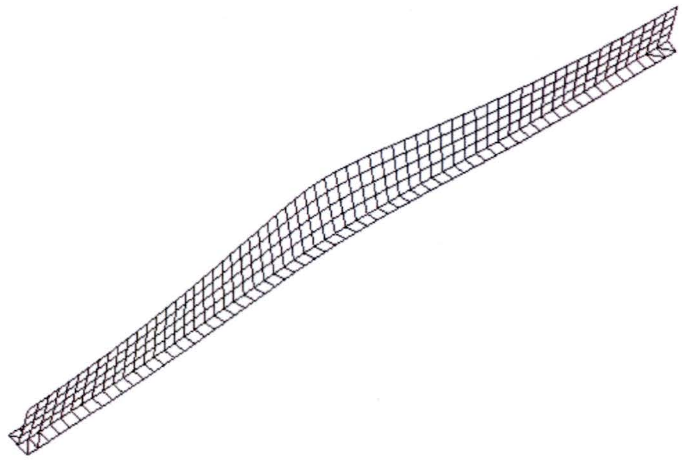

Figure 2-113. Lifting Bar First Buckling Mode – Model AOS-100

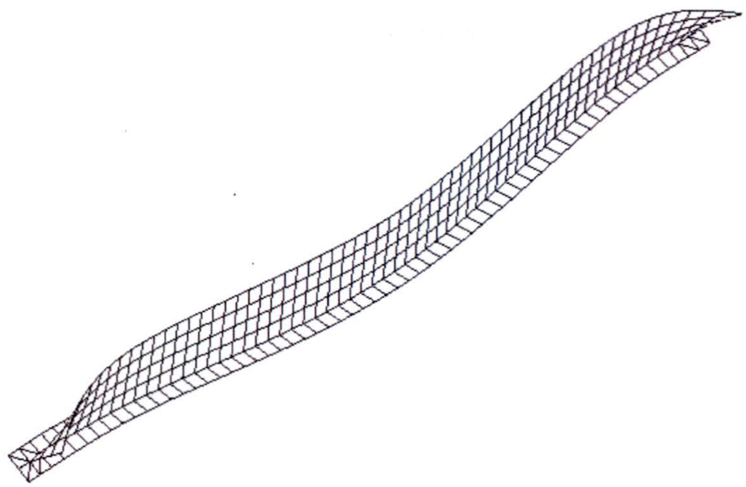

Figure 2-114. Lifting Bar Second Buckling Mode – Model AOS-100

2.12.15 Shielding/Spacer Component Evaluation – Models AOS-050A, AOS-100A, and AOS-100A-S

The axial shielding plates and cavity spacer plates generically refer to shoring components that are added within the Model AOS-050A, AOS-100A, and AOS-100A-S cask cavity for specific isotope shipping configurations, as listed in Table 2-357.

Table 2-357. Additional Required Shoring Components – Models AOS-050A, AOS-100A, and AOS-100A-S

Model	Component	Certification Drawing[a]	Material of Construction	Required for Isotope Shipments of[b]	Description
AOS-050A	Axial Shielding Plates	183C8519	Stainless Steel	Ir-192 Ir-194	Used to offset the cask contents from the cask plug and cask bottom. This dual-purpose shoring component provides both spacing (that is, distance) and supplemental shielding of the cask contents.
AOS-100A AOS-100A-S	Axial Shielding Plates	183C8491	Tungsten Alloy	Co-60-B Co-60-C	Used to offset the cask contents from the cask plug and cask bottom. This dual-purpose shoring component provides both spacing (that is, distance) and supplemental shielding of the cask contents.
	Cavity Spacer Plates	183C8518	Stainless Steel –or– Aluminum[c]	Co-60-C	Used to offset the supplemental axial shielding plates and cask contents from the cask plug and cask bottom, which provides spacing necessary to meet regulatory dose rate limits.

a. *Refer to Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models," for drawing revision levels.*

b. *As per Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models," and Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models."*

c. *Refer to Section 2.12.15.4 for details.*

Figure 2-115 illustrates the Model AOS-100A configuration when the axial shielding plates and cavity spacer plates are used. Each cavity spacer plate fills the void above or below the upper or lower axial shielding plate, respectively, with only a small gap on the diameter, which prevents the axial shielding plates from shifting during Normal conditions and Hypothetical Accident conditions of transport.

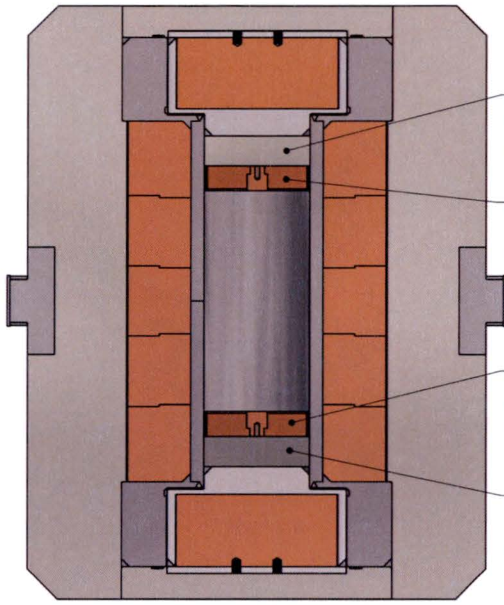

Figure 2-115. Model AOS-100A-S with Axial Shielding Plates and Cavity Spacer Plates

Note: *Model AOS-100A-S is shown. For Model AOS-100A, the lower axial shielding plate is inverted.*

2.12.15.1 Fabrication Criteria

Regulatory Guide 7.11 and *NUREG/CR-1815* (References [2.30] and [2.31], respectively), which categorize components based on the cask design's maximum activity level, govern the cavity spacer plate's fabrication. Because AOS casks are used to ship isotopes with activities greater than 3,000 A_2, the axial shielding plates and cavity spacer plates are fabricated as Category I components.

From *NUREG/CR-3854* (Reference [2.24]), the criteria for fabricating metal shipping container components that are to be used for the transport of radioactive materials are based on *ASME Code Section III* –or– *Section VIII* (References [2.26] and [2.29], respectively). The requirements for Category I components are as follows:

- Acceptance criteria for the fabrication of metal shipping container components are located in *ASME Code Section III*, as follows:
  - **Containment components** – *Subsection NB*
  - **Criticality components** – *Subsection NG*
  - **Other safety components** – *Subsection NF*
- Model AOS-050A axial shielding plates are relied on for shielding, which falls under the "Other Safety" Component Safety Group. Therefore, the Model AOS-050A axial shielding plates shall be fabricated to *ASME Code Section III, Subsection NF* –or– *Section VIII, Division 1* (References [2.26] and [2.29], respectively). For this evaluation the stress criteria presented in *Section III, Subsection NF* are used.

2.12.15.2 Component Safety Classification According to Importance to Safety

The Model AOS-050A axial shielding plates and Model AOS-100A/AOS-100A-S cavity spacer plates are required to reduce external radiation doses to levels acceptable for transport:

- For Model AOS-050A, the axial shielding plates perform the function of gamma shielding for the transport of Ir-192 and Ir-194
- For Models AOS-100A and AOS-100A-S, the cavity spacer plates offset the gamma shielding, which provides necessary spacing for the transport of Co-60-C quantities

Thus, the Model AOS-050A axial shielding plates and Model AOS-100A/AOS-100A-S cavity spacer plates are Category B items, in accordance with *NUREG/CR-6407, Section 5.3.2* (Reference [2.32]).

2.12.15.3 Stress Criteria

ASME Service Levels A and D are used for Normal conditions and Hypothetical Accident conditions of transport, respectively. The analyses methods and stress criteria allowed by *ASME Code Section III* (Reference [2.26]) are used, as follows:

- Allowable stresses are based on *Subsection NF-3200*
- Normal conditions of transport (Service Level A) design limits are defined in *Paragraph NF-3221.1*
- Hypothetical Accident conditions of transport (Service Level D) design limits are defined in *Appendix F*

Table 2-358 lists the stress criteria.

Table 2-358. Stress Criteria – Models AOS-050A, AOS-100A, and AOS-100A-S

ASME Class 1 Design[a]	Stress Limits[b]
Normal Conditions of Transport Service Level A *(Subsection NF-3221.1)*	$P_m \leq S_m$ $P_m + P_b \leq 1.5S_m$
Bearing Loads Service Level A *(Subsection NF-3223.1)*	S_y at temperature
Pure Shear Service Level A *(Subsection NF-3223.2)*	$0.6S_m$
Bearing Loads Service Level D *(Appendix F-1332.3)*	Except for pinned and bolted joints, bearing stresses need not be evaluated for loads for which Level D Service Limits are specified
Pure Shear Service Level D *(Appendix F-1332.4)*	$0.42S_u$
Hypothetical Accident Conditions of Transport Service Level D *(Appendix F-1332)*	$P_m > 1.2S_y$ and $1.5S_m < 0.7S_u$ $P_m + P_b < 150\%$ of the limit for general primary stress intensity P_m

a. *ASME Code Section III (Reference [2.26]).*

b. *P_m = Primary membrane stress intensity*
P_b = Primary bending stress intensity
S_m = Design stress intensity
S_y = Yield strength
S_u = Ultimate strength

2.12.15.4 Model AOS-050A Axial Shielding Plate and Model AOS-100A/AOS-100A-S Cavity Spacer Plate Stress Evaluation

Because of the tight fit within the cask cavity, the maximum possible stress induced in the Model AOS-100A/AOS-100A-S cavity spacer plates occurs during the end drop, in the form of a bearing load. The associated bearing stress is:

$$\sigma_b = P/A$$

where:

P	=	Inertial load divided by the projected area
A	=	Cavity spacer plate

As noted in Table 2-358, bearing stresses are evaluated only during Normal conditions of transport. However, to provide a bounding analysis of the axial shielding plate and cavity spacer plate stresses, the accelerations associated with Hypothetical Accident conditions of transport, along with an additional dynamic load factor (DLF), are applied to calculate the inertial load. Acceleration results are used from Load Case 304, 30-ft. Head-On Drop at -40°F, Low Temperature, as defined by Table 2-45. Additionally, to provide flexibility in the Model AOS-100A/AOS-100A-S cavity spacer plate design, the margin of safety is calculated based on the properties of aluminum at a bounding temperature of 400°F. (Refer to Table 3-3, "Maximum Temperature Summary, Normal Conditions of Transport – All Models.")

Table 2-358 summarizes the stress evaluation for the Model AOS-050A axial shielding plates and Model AOS-100A/AOS-100A-S cavity spacer plates. As the table shows, the calculated margin of safety is positive, which indicates that the Model AOS-050A axial shielding plates and Model AOS-100A/ AOS-100A-S cavity spacer plates will maintain functionality during Normal conditions and Hypothetical Accident conditions. The evaluation also shows that the Model AOS-100A/AOS-100A-S cavity spacer plates can be fabricated from aluminum or stronger material, such as stainless steel.

Table 2-359. Model AOS-050A Axial Shielding Plate and Model AOS-100A/AOS-100A-S Cavity Spacer Plate Stress Calculation Summary

Description	Identifier	Model AOS-100A/ AOS-100A-S Cavity Spacer Plate	Model AOS-050A Axial Shielding Plate
Acceleration[a] (Hypothetical Accident Conditions of Transport)	G	276.1 g	566.2 g
Contents	pc	500 lbs.	60 lbs.
Diameter	d	6 in.	3.125 in.
Area ($\pi \times d^2/4$)	A	28.3 in^2	7.7 in^2
Inertia Load (G × pc × DLF)	P	138,050.0 lbs.	33,972.0 lbs.
Dynamic Load Factor	DLF	2	2
Bearing Stress	σ_b	9,765.0 psi	8858.5 psi
Component Temperature	–	312°F	296°F
Yield Strength ASME SB-209 Alloy 6061 T6 at 400°F[b]	F_y	13,300 psi	13,300 psi
Margin of Safety	MS	0.4	0.5

a. *Refer to Table 2-52 and Table 2-50, respectively.*

b. *As per ASME Code, Section II, Part D* **[2.5]**.

3 THERMAL EVALUATION

This chapter identifies, describes, discusses, and evaluates the principal thermal engineering design of the packaging, components, and systems important to safety, and describes how the package complies with the performance requirements specified by *10 CFR 71* [3.1] and *IAEA TS-R-1* [3.2].

The evaluation accomplishes this objective by determining the temperature distributions within the transport package during Normal conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport. Additionally, the thermal results are compared against the performance requirements and temperature limits of the materials used. The approach taken assures the safe operation of the package.

3.1 DESCRIPTION OF THERMAL DESIGN

The AOS Transport Packaging System is designed with a thermally passive system to provide adequate thermal performance under Normal and Hypothetical Accident conditions of transport relying solely upon the design capacity to transmit and dissipate heat to the outside environment. The cask component is enclosed at both ends by an impact limiter structure, which functions as a thermal shield and mitigates regulatory impact loads, per regulatory requirements. In the case of the Model AOS-025, the impact limiter component of the AOS Transport Packaging System completely encloses the cask.

3.1.1 Design Features

The AOS Transport Packaging System consists of three (3) main components: (a) cask; (b) impact limiters; and (c) cask lid seal. Materials of construction are 300 series stainless steel (SS300) for structural members of the packaging; tungsten alloy or carbon steel for shielding material inserts; polyurethane foam for thermal shielding and impact load mitigation; and selected silicone/SS300 series for the cask lid elastomeric seal and silver/nickel-chromium alloy/SS304L combination for the Helicoflex® cask lid metallic seal. Refer to Section 1.2, "Package Description," for further details regarding these main and other minor components. Principal packaging dimensions are presented in Table 1-1, "AOS Transport Packaging System Dimensions and Maximum Authorized Package Weight – All Models."

Due to fabrication dimension tolerances, there is a series of gaps throughout the cask body. To minimize their impact upon the heat transfer characteristics of this component, the largest gaps are either packed with stainless steel wool or shim stock. The conservative approaches taken for the treatment of these gaps within the analytical model are discussed further in this chapter.

The temperature distributions for the AOS Transport Packaging System models are determined for the thermal environments listed in Table 3-1.

All thermal conditions were analyzed using the LIBRA Finite Element program, with the exception of Thermal Conditions 5 and 7, where uniform temperature fields of -40°C and -29°C (-40°F and -20°F, respectively) were assigned. A description of the LIBRA Finite Element program heat transfer module is provided in Appendix 3.5.3, which also includes the qualifications and verification program conducted by GE to support the modeling techniques and assumptions taken throughout the thermal evaluation. To further verify the thermal model, a heat test was conducted, using a 165%-scaled geometry of the Model AOS-100A transport package. In this test, a 7-kW electrical heat source was placed inside the cask cavity. The cask was then closed and placed within a pit. Placing the cask inside the pit helped to maintain the environment temperature constant. Temperatures inside and outside of the cask, and the ambient temperature inside the pit, were recorded during the cask heating and cooling cycles. Refer to Appendix 3.5.7 for a detailed account of the heat test and its results.

The maximum decay heat for each AOS Transport Packaging System model is distributed across the cask cavity surface. Condition 3 (fire transient) analysis is initiated at the steady-state Condition 1, in which the maximum solar load is applied.

Table 3-1. Transport Package Thermal Environment Conditions – All Models

Condition	Conditions of Transport	Thermal Environment
1	Normal	38°C (100°F) ambient with maximum decay heat and maximum solar load.
2	Normal	38°C (100°F) ambient with maximum decay heat.
3	Hypothetical Accident (Fire)	Fire transient, t = 0 to 8.0 hours.
4	Normal	-40°C (-40°F) ambient with maximum decay heat.
5	Normal	-40°C (-40°F) ambient.
6	Normal	-29°C (-20°F) ambient with maximum decay heat.
7	Normal	-29°C (-20°F) ambient.

3.1.2 Contents' Decay Heat

Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models," and Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models," provide the maximum decay heat and radioactivity for the AOS Transport Packaging System contents. This includes Decay Heat (Ci/W) values for each radioisotope listed, showing that the decay heat is consistent with the maximum quantity of radioactivity contents. A summary of the Decay Heat values is shown in Table 3-2.

Table 3-2. Contents' Decay Heat – All Models

Model	Contents' Decay Heat (W)
AOS-025A	10
AOS-050A	100
AOS-100A	400
AOS-100B	400
AOS-100A-S	400

4 CONTAINMENT

This chapter identifies the AOS Transport Packaging System containment systems and describes how the Packages comply with the containment requirements of *10 CFR 71* **[4.1]**, under Normal conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport, as well as *49 CFR 173* **[4.2]**, and the *International Atomic Energy Agency Safety Standards Series No. TS-R-1 (IAEA TS-R-1)* **[4.3]**.

4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

This section identifies and describes the AOS Transport Package containment systems, including the welds, seals, lids, cover plates, and closure devices. The AOS Transport Packaging System is designed to meet the "leak-tight" criteria specified the American National Standards Institute, *ANSI N14.5-1997* **[4.4]**, for the transportation of activated material in *Normal* and *Special form*.

4.1.1 Containment Boundary

The AOS transport package containment boundary (located within the cask of the transport package) is composed of the following:

- Cask cavity shell
- Containment penetrations or port plug sub-assemblies
- Cask lid elastomeric and metallic seal components of the AOS Transport Packaging System cask

The containment boundary loops along the cask cavity shell walls and port plug walls, across the port opening, between its pipe plug and plug cover, through the cask lid material and across the cask lid seal joint between the two (2) retainer rings (elastomeric seal) or "C" cross-sections (metallic seal). The dashed lines in Figure 4-1 illustrate the containment boundary (located within the cask unit of the transport package).

The cask unit is constructed of 300 series stainless steel (SS300) material. Tungsten alloy or carbon steel material is embedded within the cask body and cask lid plug, to enhance the assembled cask shielding capability. Shielding material options are variable within the AOS Transport Packaging System models. There are two (2) penetrations into the cavity region of the cask – the cask drain port and cask vent port. These ports are comprised of a lower seal, a threaded pipe plug, a silicone material O-Ring, and a port cap, as discussed in Section 4.1.2.

The cask lid seals use either a pair of elastomeric O-Rings captured within one (1) or two (2) SS300 series flat rings, or a metallic double "C" cross-section arrangement, as discussed in Section 4.1.3. Figure 4-1 illustrates the general arrangement of these systems. The cask lid seals used on the AOS Transport Packaging System models are included in Appendix 4.5.1.

5 SHIELDING EVALUATION

This chapter identifies, describes, discusses, and analyzes the AOS cask's principal radiation shielding design, which is important to safety.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The cask is a cylindrical container with a cylindrical cavity in which radioactive materials are placed. Tungsten alloy or carbon steel shields (depending on model) for radiation attenuation are located on the cask cavity's top, bottom, and sides. Figure 5-1 illustrates the main cask components.

Cask components important to shielding, including the radiation shields and cask cavity, are discussed in this subsection. For all shielding evaluations, the impact limiter is ignored. Other transport package design features, such as the shipping cage, securing lines, and internal structure, are irrelevant from a shielding perspective and are also not considered. The absence of these components in the shielding model helps ensure a bounding dose rate estimate. For the dose rate location, however, the impact limiters are important because they move the normal shipping configuration-accessible surface away from the cask surface. This distance is included in the dose rate location selection; however, the materials occupying the impact limiter space are neglected.

Tests applied to the packaging and its contents, under Normal conditions of transport (NCT) and Hypothetical Accident conditions (HAC) of transport, demonstrated that the cask components modeled can maintain their structural integrity for all considered events. This allowed a single geometric model to be developed for each cask size being considered.

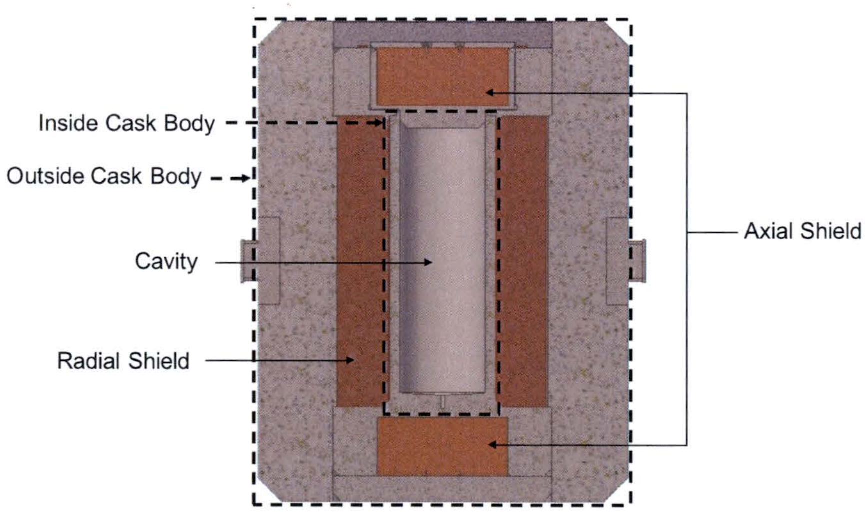

Figure 5-1. Cross-Sectional View of Cask Components

Table 5-1 lists the outside radius and half-height of each model's cask components. The half-height is the distance from the cask's center to the component's top, as illustrated in Figure 5-2. For example, the Model AOS-100's actual cavity height is 50.80 cm (20.00 in.), and the thickness of its axial shield is 11.13 cm (4.38 in.). This is calculated using Equation 5-1. Each cask is symmetric about the cask centerline, as illustrated in Figure 5-2. Dimensions for additional cask details that are included in the shielding models, such as beveling on the cask body corners and the radial shields, are as listed in the certification drawings. (Refer to Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models.")

$$h_{axial\_shield} = HalfHeight_{axial\_shield} - HalfHeight_{inner\_cask\_body} \tag{5-1}$$

Table 5-1. Cask Component Dimensions, Outside Radius and Half-Height – All Models[a]

Model	Component	Outside Radius		Half-Height[b]	
		cm	in.	cm	in.
AOS-025	Cavity	2.06	0.81	6.35	2.50
	Inside Cask Body	2.59	1.02	7.41	2.92
	Radial Shield	5.03	1.98	6.93	2.73
	Axial Shield	3.15	1.24	10.19	4.01
	Outside Cask Body	8.89	3.50	11.43	4.50
AOS-050	Cavity	4.13	1.63	12.70	5.00
	Inside Cask Body	5.18	2.04	14.84	5.84
	Radial Shield	10.06	3.96	13.84	5.45
	Axial Shield	6.30	2.48	20.40	8.03
	Outside Cask Body	17.78	7.00	22.86	9.00
AOS-100	Cavity	8.26	3.25	25.40	10.00
	Inside Cask Body	10.36	4.08	29.62	11.66
	Radial Shield	20.12	7.92	27.71	10.91
	Axial Shield	12.60	4.96	40.74	16.04
	Outside Cask Body	35.56	14.00	45.72	18.00

a. *Dimensions are rounded.*

b. *Axial distance from cask centerline.*

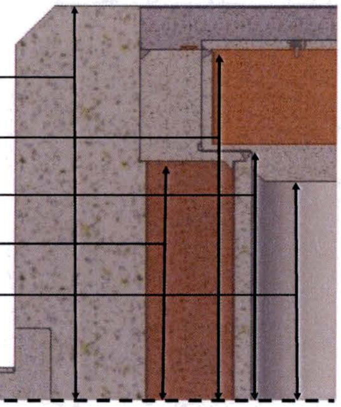

Figure 5-2. Cask Component Half-Height – All Models

Table 5-2 lists the cavity height and axial shield thickness for each AOS Transport Packaging System model.

Table 5-3 lists the materials for each cask component that is important to shielding. Tungsten alloy is used as the shielding material in casks whose model numbers include the suffix A. Carbon steel is used as the shielding material in casks whose model numbers include the suffix B. Therefore, the only difference between the Model AOS-100A and AOS-100B transport packages is the shielding material. The tungsten alloy density and minimum weight fraction of elemental tungsten are based on Class 3 tungsten in *AMST 21014* (Reference **[5.6]**).

Table 5-2. Cask Component Dimensions, Cavity Height and Axial Shield Thickness – All Models

Model	Component	Dimensions	
		cm	in.
AOS-025A	Cavity Height	12.70	5.00
	Axial Shield Thickness	2.77	1.09
AOS-050A	Cavity Height	25.40	10.00
	Axial Shield Thickness	5.56	2.19
AOS-100A AOS-100B AOS-100A-S	Cavity Height	50.80	20.00
	Axial Shield Thickness	11.13	4.38

Table 5-3. Cask Component Materials Important to Shielding – All Models

Component	Material	Model Type		Material Composition		Density (g/cm^3)
		AOS-025A AOS-050A AOS-100A	AOS-100B	Element	Weight Fraction	
Shield	Tungsten Alloy	✔		Tungsten	0.9500	17.75
				Nickel	0.0350	
				Iron	0.0150	
	Carbon Steel		✔	Carbon	0.0050	7.82
				Iron	0.9950	
Cask	Stainless Steel	✔	✔	Iron	0.7200	8.0
				Manganese	0.0200	
				Chromium	0.1800	
				Nickel	0.0800	

5.1.2 Summary Table of Maximum Radiation Levels

Table 5-4 and Table 5-5 list the maximum dose rates for both Normal conditions and Hypothetical Accident conditions of transport, at the appropriate locations for non-exclusive or exclusive use (or both), as applicable. A conservative 10% reduction in allowable *10 CFR 71.47 (a)* dose rate limits (Reference [5.1]) is applied for maximum radiation levels.

Table 5-4. Maximum Radiation Level Summary for Normal Conditions of Transport – All Models

Normal Conditions of Transport	External Surface[a] (mrem/hr)	1m from External Surface[a] (mrem/hr)
Gamma Radiation	180	9
Neutron Radiation	0	0
Total	180	9
10 CFR 71.47(a) Limit [5.1]	200	10[b]

a. *For this analysis, the external surface is considered to be the deformed impact limiter surface.*

b. *Transport index may not exceed 10.*

Table 5-5. Maximum Radiation Level Summary for Hypothetical Accident Conditions of Transport – All Models

Hypothetical Accident Conditions of Transport	1m from External Surface[a] (mrem/hr)
Gamma Radiation	370.27
Neutron Radiation	0
Total	370.27
10 CFR 71.51(a)(2) Limit [5.1]	1,000

a. *For this analysis, the external surface is considered to be the cask surface.*

5.2 SOURCE SPECIFICATION

Table 5-6 lists the activation products to be loaded in the AOS transport package, for each transport package model. For any single shipment, only one isotope may be loaded into the cask. The exceptions to this rule are that Ir-194 impurities may be present in shipments of Ir-192, in quantities as designated in Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models," and Nb-95 may be loaded with Zr-95, but only as outlined in Subsection 5.2.1.

Because of the penetration power of neutral radiation, such as gamma rays, these were the main concern for shielding calculations. Charged particles, such as alpha and beta particles, are not able to penetrate the cask's thick shield layers, and the assumption was made to ignore these charged particles and their secondary particles (such as bremsstrahlung photons induced by beta particles) for shielding evaluations.

Table 5-6. Isotopes Analyzed for AOS Transport Packages – All Models

Isotope	Model		
	AOS-025	AOS-050	AOS-100
Co-60	✔	✔	✔
Cs-137	✔	✔	✔
Hf-181		✔	✔
Ir-192	✔	✔	✔
Ir-194	✔	✔	✔
Zr/Nb-95		✔	✔
Ho-166	✔	✔	
Yb-169	✔	✔	

5.2.1 Gamma Source

The source description for activation products is obtained from isotope decay schemes that detail the gamma particle energies and their absolute probabilities of emission per disintegration (decay). For all isotopes except Zr/Nb-95, these decay schemes are explicitly modeled in the cask, based on discrete gamma energy and emission probability source terms extracted from the SCALE 6.1 ORIGEN (Reference **[5.2]**) gamma spectrum library *origen.rev04.mpdkxgam.data*. All available gamma energies from the library are considered in the shielding calculations. Total photon/decay values are also calculated and used, based on the information contained in the gamma spectrum library, by summing the total absolute probability of emission, per decay, from all possible energies for a given isotope.

Table 5-23 through Table 5-31 in Appendix 5.5.2 list the source spectra used in the shielding models.

The dose rate analysis is performed only on gamma-ray shielding by neglecting the transport of charged particles. Because charged particles do not have the same penetrating abilities as neutral particles, their energy losses are assumed to be deposited in the shielding material in the form of heat. The production and transport of secondary particles from charged particles (such as bremsstrahlung photons generated by beta particles in the shielding materials) is also neglected. This assumption is valid if the energies and/or emission probabilities of secondary particles are negligible, compared to those of primary gamma rays.

The Zr/Nb-95 source is handled differently than the other radionuclides (the source spectra are combined). This is the case because the activity limit provided in Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models," for the parent/daughter isotope system (Zr/Nb-95) applies only to the parent isotope (Zr-95). The only source of Nb-95 in a shipment must be from a decay of Zr-95. Because this is the case, the maximum amount of Nb-95 relative to Zr-95 occurs when the isotopes are in equilibrium. By assuming Nb-95 exists in equilibrium with Zr-95 in any shipment, the total system activity is maximized. The parent and daughter's activity ratio at equilibrium is determined using Equation 5-2.

$$\frac{A_{Nb}}{A_{Zr}} = \frac{\lambda_{Nb}}{\lambda_{Nb} - \lambda_{Zr}} = 2.20 \tag{5-2}$$

where:

A_{Nb}	=	Activity of Nb (daughter)
A_{Zr}	=	Activity of Zr (parent)
λ_{Nb}	=	Nb decay constant
λ_{Zr}	=	Zr decay constant

Thus, a maximum of 2.2 decays from Nb-95 occur for every one decay from Zr-95. Equation 5-2 is confirmed using basic Bateman equations. For conservatism, the total number of decays per Becquerel of Zr-95 is assumed to be the total from both Nb-95 and Zr-95. This is equivalent to 3.2 photons per Becquerel of Zr-95. The fact that the dominant decay energies from both isotopes are very close allows for the use of a single, bounding decay energy of 0.766 MeV to be assumed for the isotope mixture.

Table 5-23 and Table 5-29 in Appendix 5.5.2 list the source spectra used for Zr/Nb-95 in the shielding models.

The Ir-192/Ir-194 sources each use their own spectra, which is the same as the other radionuclides. Ir-192/Ir-194 are handled differently from the other radionuclides in post processing (the dose rates are combined). This is discussed in Section 5.4.4.

5.2.2 Neutron Source

Not applicable. Neutron-emitting materials are not authorized for this transport package design.

5.3 SHIELDING MODEL

5.3.1 Configuration of Source and Shielding

5.3.1.1 Cask Shielding

An explicit 3D cask model, representative of the dimensions tabulated in Table 5-1 and Table 5-2, was developed using the particle transport code *Monte Carlo N-Particle (MCNP6)*. Use of these nominal dimensions to define the shield model is consistent with standard engineering practices. The increase in possible dose rates, due to the small tolerances on these dimensions, is bounded by the 10% reduction in allowable dose limits described in Subsection 5.1.2. The impact limiter, shipping cage, and any internal or external shoring components were modeled as air, for conservatism. A sketch of the cask components modeled is provided in Figure 5-1. Tests applied to the packaging and their contents, under Normal conditions and Hypothetical Accident conditions of transport, demonstrated that the cask components modeled maintained their structural integrity for all considered events. This allowed a single geometric model to be developed for each cask size that is being considered. Figure 5-3 illustrates the base MCNP6 geometry used for modeling the AOS casks.

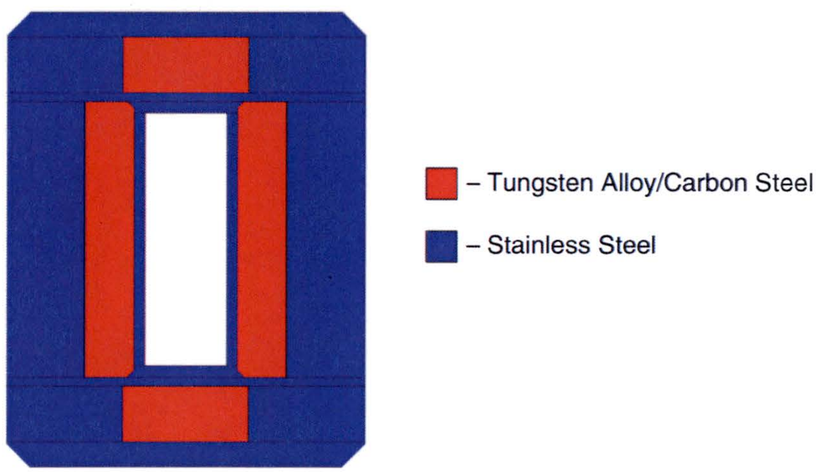

Figure 5-3. MCNP6 Geometry Model

5.3.1.2 Shielding/Spacer Components

Additional components have been designed to allow for activity limits that are desired for each cask. These additional components, for each cask size (Models AOS-025, AOS-050, and AOS-100), are placed inside the cask cavity to provide additional shielding and/or spacing, depending on the model. Table 5-7 summarizes the additional components that are used for each cask. All additional components are modeled in MCNP6 per the dimensions in their respective certification drawings. (Refer to Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models.")

For all isotopes transported in the Model AOS-025, the tungsten alloy liner shown in certification drawing 183C8485 must be used. The contents to be shipped are loaded into the liner, which is then closed and loaded into the Model AOS-025. The stress analysis for this tungsten alloy liner is presented in Paragraph 2.5.3.3.1, "Stress Analysis of Cavity Liner – Model AOS-025," where it is demonstrated that the liner is capable of surviving any Normal or Hypothetical Accident conditions of transport.

For shipments of Ir-192 and Ir-194 in the Model AOS-050, the stainless steel axial shielding plates shown in certification drawing 183C8519 are used. For this configuration, the contents are loaded into the Model AOS-050 cavity in between the two axial shielding plates so that the plates provide shielding and spacing for dose rates exiting the cask's top and bottom. The MCNP6 models for this configuration include a 3/8-in. hole through each plate's center in consideration of penetrations that will be needed for handling (such as a screw hole). Although the hole in the shielding model is through the entire plate, a requirement for loading the plates is that this screw hole must be filled with a setscrew during shipment. The structural evaluation for the Model AOS-050 axial shielding plates is provided in Appendix 2.12.15, "Shielding/ Spacer Component Evaluation – Models AOS-050A, AOS-100A, and AOS-100A-S," where it is demonstrated that the plates are capable of surviving any Normal or Hypothetical Accident conditions of transport. However, for the Model AOS-050 shielding analysis, it is assumed that these stainless steel axial shielding plates are destroyed in Hypothetical Accident conditions of transport and no credit is taken for additional spacing or shielding provided.

For Co-60-B quantities of material in Models AOS-100A and AOS-100A-S, the tungsten alloy axial shielding plates in certification drawing 183C8491 are used. For this configuration, the contents are loaded in the Model AOS-100A/AOS-100A-S cavity, between the two axial shielding plates, so that the plates provide shielding and spacing for dose rates exiting the cask's top and bottom. The structural evaluation for the Model AOS-100A/AOS-100A-S axial shielding plates is provided in Paragraph 2.5.3.3.2, "Stress Analysis of Axial Shielding Plate – Models AOS-100A and AOS-100A-S," where it is demonstrated that the plates are capable of surviving any Normal or Hypothetical Accident conditions of transport.

For Co-60-C quantities of material in Models AOS-100A and AOS-100A-S, the stainless steel or aluminum cavity spacer plates shown in certification drawing 183C8518 and the tungsten alloy axial shielding plates shown in certification drawing 183C8491 are used. For this configuration, the contents are loaded in the Model AOS-100A/AOS-100A-S cavity, between the two axial shielding plates, with the cavity spacer plates loaded outside the axial shielding plates, such that the cavity spacer plates provide spacing between the axial shielding plates and the cask cavity's top or bottom. The cavity spacer plate materials of construction (stainless steel or aluminum) are based solely on their structural integrity. In the shielding analysis, no credit is taken for the cavity spacer plate material, only the additional distance provided. The structural evaluation for the Model AOS-100A/AOS-100A-S axial shielding plates is provided in Paragraph 2.5.3.3.2, "Stress Analysis of Axial Shielding Plate – Models AOS-100A and AOS-100A-S," where it is demonstrated that the axial shielding plates are capable of surviving any Normal or Hypothetical Accident conditions of transport. The structural evaluation for the Model AOS-100A/AOS-100A-S cavity spacer plates is provided in Appendix 2.12.15, "Shielding/Spacer Component Evaluation – Models AOS-050A, AOS-100A, and AOS-100A-S," where it is demonstrated that the cavity spacer plates are capable of surviving any Normal or Hypothetical Accident conditions of transport. However, for the shielding analysis, it is assumed that the cavity spacer plates are destroyed in Hypothetical Accident conditions of transport and no credit is taken for additional spacing provided.

Table 5-7. AOS Cask Components – All Models

Model	Isotope	Certification Drawing	Construction Material	Radial Dimension[a]		Axial Dimension[b]	
				cm	in.	cm	in.
AOS-025	All	Liner (183C8485)	Tungsten Alloy	1.40	0.55	2.15	0.85
AOS-050	Ir-192/Ir-194	Axial Shielding Plates (183C8519)	Stainless Steel	3.81	1.50	3.81	1.50
AOS-100A AOS-100A-S	Co-60-B	Axial Shielding Plates (183C8491)	Tungsten Alloy	8.10	3.19	3.81	1.50
	Co-60-C	Axial Shielding Plates (183C8491)	Tungsten Alloy	8.10	3.19	3.81	1.50
		Cavity Spacer Plates (183C8518)	Stainless Steel –or– Aluminum	8.10	3.19	4.62	1.82

a. *For the AOS-025 liner, this dimension refers to the radial thickness of tungsten alloy provided by the liner. For all cavity spacer and axial shielding plates, this dimension refers to the plate's radius.*

b. *For the AOS-025 liner, this dimension refers to the axial thickness of tungsten alloy provided individually by the liner top or bottom. For all cavity spacer and axial shielding plates, this dimension refers to the plate's thickness.*

5.3.1.3 Sources

All isotopes, except for the Co-60-C configuration, are modeled as point sources at the locations listed in Table 5-8 and identified in Figure 5-4.Each point source location is analyzed for Normal conditions and Hypothetical Accident conditions of transport. Point sources do not account for self-shielding effects due to the actual source geometry and density or for shielding due to internal components, such as source racks. By placing the point sources in these locations, the most restrictive source locations are analyzed. An actual radioactive load in the container is distributed over significantly more volume than a point source, thereby providing margin for the activity limits calculated using point sources. The point source model provides assurance that the dose rate, at locations fairly close to the source, is over-estimated. Dose rates obtained from the point source model bound the transport packages in their as-shipped configuration.

The Co-60-C corner source dose rate calculation is the only exception to this point source modeling. For this case, the source is modeled as a small volume. With a source activity, a specific activity limit, and a material density, the minimum volume through which the source would occupy is calculated. For this source configuration, it is assumed that all Cobalt material in the cask collects in the worst-case geometry – in the cask's top corner. Appendix 5.5.4 provides further details regarding source volume modeling for the Co-60-C configuration and worst-case source geometry determination.

Table 5-8. Point Source Locations[a]

Point Source Location Label	Location
Top Source	Center of the cask cavity's top edge, used for axial cases (Z axis, positive direction).
Side Source	Center of the cask cavity's radial edge, used for radial cases (Y axis, positive direction).
Corner Source	Top corner of the usable cask cavity, used for axial and radial assessment.

a. Figure 5-4 identifies each point source location.

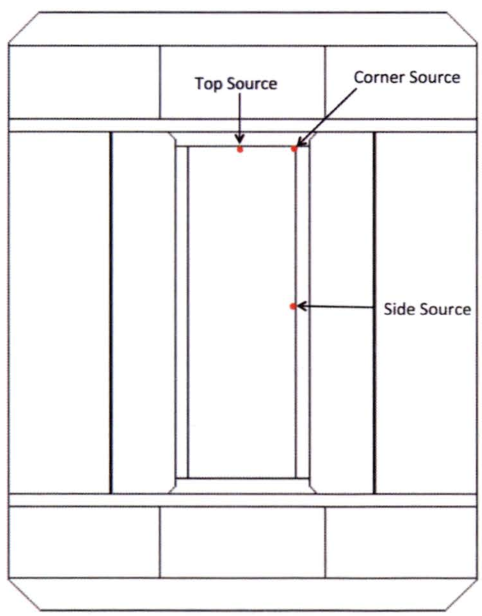

Figure 5-4. MCNP6 Point Source Locations

5.3.1.4 Tallies

Dose rates are calculated using cell tallies to determine the region of the regulatory dose rate location with the peak particle flux, and show the surrounding distribution. For the **Top Source** location, the tally cells are modeled as 1-cm-tall cylinders, increasing in radius, that are rotationally symmetric about the Z axis. Tor the **Side Source** location, the tally cells are modeled as 1-cm-thick arcs with an internal angle of 10° from the cask center. For the **Corner Source** location, the axial and radial external surface tallies are extended to the point at which they meet, and the 1-m (40-in.) transport index and 1 m (40 in.) Hypothetical Accident conditions of transport tally cells are curved such that every cell is 1 m (40 in.) from the respective surface (that is, impact limiter or cask). Figure 5-5 through Figure 5-7 illustrate the MCNP6 models for the top, side, and corner source locations, respectively, with the tally cells labeled for the External Surface, HAC, and Transport Index dose rate calculations. From these figures, the dimensions ES_{ax} and ES_{rad} are defined in Table 5-11 and Table 5-12.

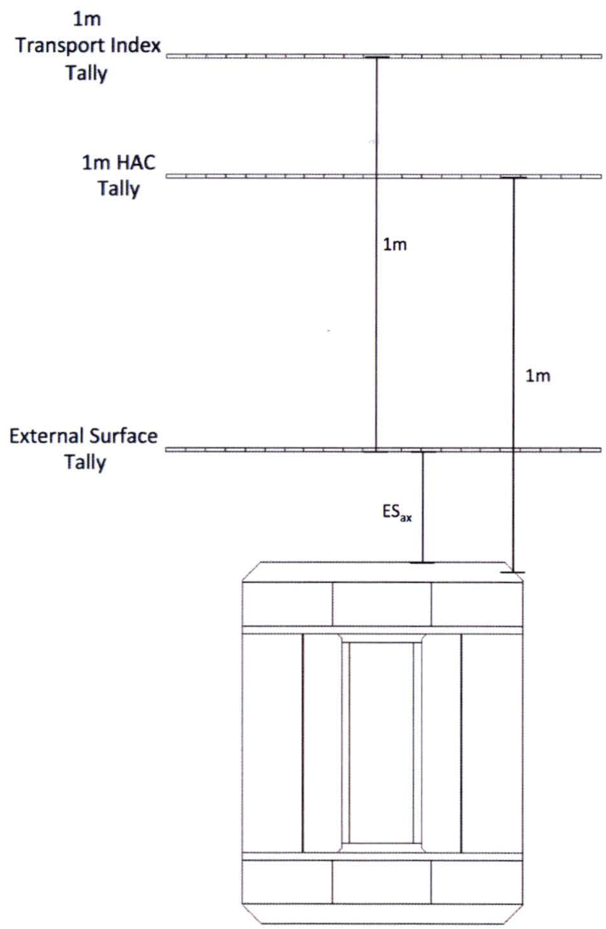

Figure 5-5. Shielding Model Tallies for Top Source Location

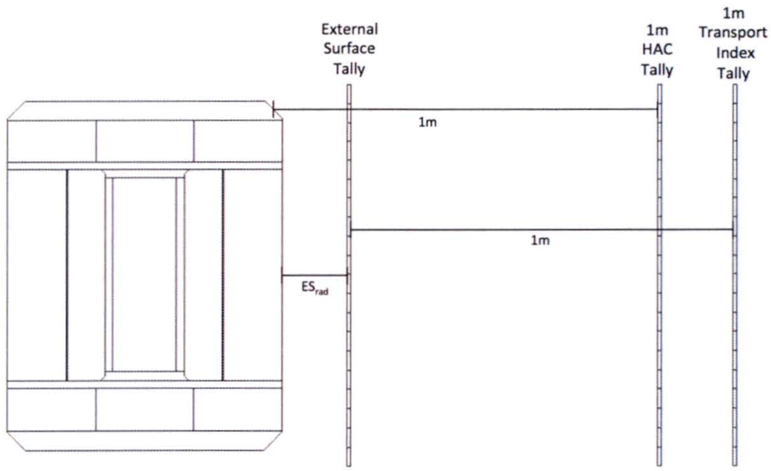

Figure 5-6. Shielding Model Tallies for Side Source Location

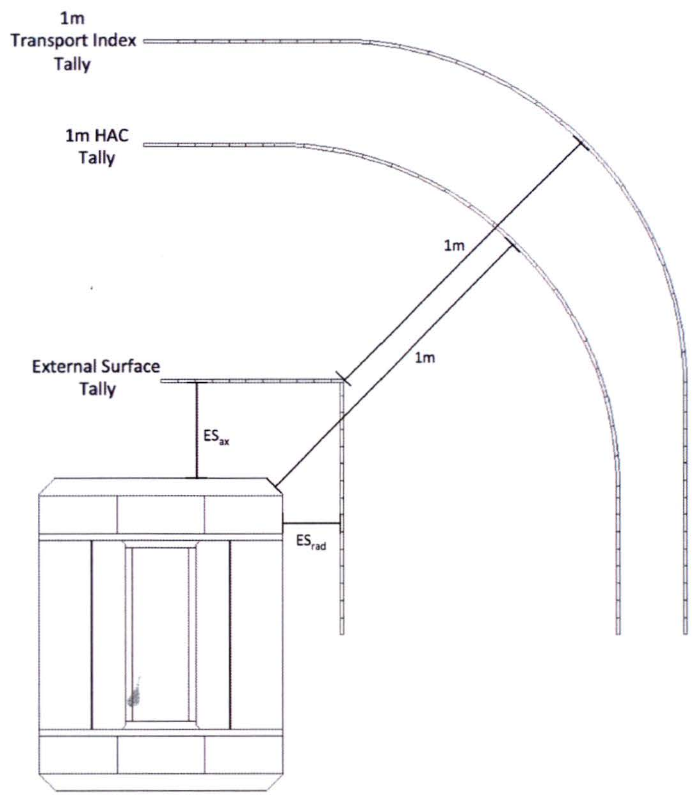

Figure 5-7. Shielding Model Tallies for Corner Source Location

The selection of dose rate locations is based on the impact limiter's deformed surface, which is considered the external package surface under Normal conditions of transport. The impact limiter's crushed and deformed surface creates the closest accessible area during transit and, therefore, is used to calculate the dose rate from radioactive contents under Normal conditions of transport. The maximum deformations in the impact limiter surfaces resulting from an End Drop (axial direction) or Side Drop (radial direction) consistent with Normal conditions of transport are provided in Chapter 2, "Structural Evaluation," for all AOS transport package models. The external surface deformations used in dose calculations, as provided in Table 5-9 and Table 5-10, bound the maximum end and side deformations. For the corner source case, the cumulative deformation from a Normal conditions of transport side and end drop is included for the tally locations.

Table 5-11 and Table 5-12 define the distances from the cask center to the dose rate locations that are used to evaluate the external surface radiation levels, and 1m (40 in.) from the cask and from the external surface.

It is assumed that the notch at the end of the impact limiter is not accessible during Normal conditions of transport. This assumption is based on the fact that the shipping cage on top and pallet on bottom will be pushed against the notch on the impact limiter in the case of an End Drop.

Table 5-9. External Surface Deformation Used for Dose Calculation in Axial Direction – End Drop

	Impact Limiter Half-Height		Impact Limiter End Drop Deformation		Deformed Impact Limiter Half-Height	
Model	**cm**	**in.**	**cm**	**in.**	**cm**	**in.**
AOS-025	20.64	8.13	1.52	0.60	19.11	7.53
AOS-050	40.23	15.84	3.81	1.50	36.27	14.34
AOS-100	80.42	31.66	6.60	2.60	73.81	29.06

Table 5-10. External Surface Deformation Used for Dose Calculation in Radial Direction – Side Drop

	Impact Limiter Radius		Impact Limiter Side Drop Deformation		Deformed Impact Limiter Radius	
Model	**cm**	**in.**	**cm**	**in.**	**cm**	**in.**
AOS-025	14.42	5.68	0.97	0.38	13.45	5.30
AOS-050	28.84	11.36	3.05	1.20	25.79	10.16
AOS-100	57.71	22.72	5.08	2.00	52.63	20.72

Table 5-11. Distances from Center of Cask Used for Dose Calculations – Axial Location

Model	External Surface[a] (ES_{ax})		1m from Cask Surface		1m from External Surface[a]	
	cm	in.	cm	in.	cm	in.
AOS-025	19.11	7.53	110.85	43.64	119.11	46.90
AOS-050	36.42	14.34	121.70	47.92	136.42	53.71
AOS-100	73.81	29.06	143.41	56.46	173.81	68.43

a. For this analysis, the external surface is considered to be deformed.

Table 5-12. Distances from Center of Cask Used for Dose Calculations – Radial Location

Model	External Surface[a] (ES_{rad})		1m from Cask Surface		1m from External Surface[a]	
	cm	in.	cm	in.	cm	in.
AOS-025	13.45	5.30	108.31	42.64	113.45	44.67
AOS-050	25.79	10.16	116.62	45.91	125.79	49.53
AOS-100	52.63	20.72	133.25	52.46	152.63	60.09

a. For this analysis, the external surface is considered to be deformed.

5.3.2 Material Properties

Material compositions and densities used in the AOS casks are provided in Table 5-3. All material compositions are modeled in the shielding evaluation, as prescribed in Table 5-3.

5.4 SHIELDING EVALUATION

5.4.1 Methods

MCNP6 (Reference [5.3]), a general-purpose Monte Carlo N-Particle transport code developed by Los Alamos National Laboratory, is used to calculate the AOS cask dose rates. The code has the capability of simulating neutron, photon, electron, or coupled neutron/photon/electron transport, in an arbitrary 3D geometric configuration of materials.

MCNP6 for photon transport uses continuous-energy atomic data libraries (ENDF/B-VI.8) (Reference [5.4]) for all elements from Z = 1 through Z = 100. The data in the photon interaction tables allow MCNP6 to account for coherent and incoherent scattering, photoelectric absorption with the possibility of fluorescent emission, and pair production. Scattering angular distributions are modified by atomic form factors and incoherent scattering functions.

Important standard features that make MCNP6 versatile and easy to use for photon transport include a powerful general source, both geometry and output tally plotters, a rich collection of variance reduction techniques for heavy shielding problems, a flexible tally structure, and an extensive collection of cross-section data.

Use of MCNP6 for dose rate calculations in heavy shielding systems requires application of variance reduction techniques to obtain precise solutions in a timely manner. Correct implementation of variance reduction techniques yields the same solution with a similar statistical variance as an analog Monte Carlo simulation, but in a shorter amount of computer time.

The primary variance reduction techniques used in the MCNP6 modeling of AOS casks are:

- (1) Mesh-Based Weight Windows
- (2) Source Biasing
- (3) Exponential Transform

Each is described in the text that follows.

(1) Mesh-Based Weight Windows

Mesh-based weight window is one of particle population control methods available in MCNP6. This method helps keep the particle weight dispersion within reasonable bounds throughout the problem, by using particle splitting and roulette-style chance to control the quantity of particles taken in various regions of phase space. The mesh weight window generator makes it possible to generate an importance function, with respect to both an energy grid and/or a spatial grid that overlays the problem geometry. Particle splitting and roulette-style chance can then be played as a function of both particle position and energy.

A cylindrical or rectangular mesh is defined with various spatial resolutions in different regions, depending on the tally and the shielding material and location. To enhance the weight window generator's performance, the exponential transform and/or source biasing are used. In addition, the density reduction technique is applied to produce an initial importance function. Use of the initial importance function, with the shield density reset to its natural value, sufficiently improved the importance function through several iterations with reasonable Figure of Merit (FOM; a measure of how quickly the desired precision is achieved).

(2) Source Biasing

Source biasing is one of modified sampling methods that alter the statistical sampling of a problem to increase the quantity of tallies per particle. Source energy biasing is applied in the modeling, as needed.

Source energy biasing involves changing the source's emission energy. For some isotopes, their emission spectra have very low mean energies. It becomes extremely difficult to obtain any answer for low-energy photon transmission in a heavy shielding system. The source energy biasing used in the modeling favors the emission of source particles with higher energies, while adjusting the starting weight of each history, so that the total emitted weight of each energy line is conserved.

(3) Exponential Transform

Exponential transform is also one of modified sampling methods. Applying the exponential transform aids in the MCNP6 tally convergence by making it easier for particles to move in the desired direction by artificially reducing the cross-section in the preferred direction and then increasing the cross-section in the opposite direction. Depending on which direction the particle is travelling, its weight is adjusted so that the expected weight colliding at any tally cell is preserved. In the modeling, this method is used to allow particles more likely to enter a region containing tally cells.

5.4.2 Input and Output Data

5.4.2.1 Input Data

The MCNP6 input data includes:

- Cask's geometry and material description
- Source definition
- Variance reduction (mesh-based weight window, source biasing, and exponential transform
- Flux-to-dose rate conversion factors
- Tally cell locations

The mesh structure parameters for weight window generation and usage are defined by the MESH card in the input, which divides the transport package into coarse and fine subsections. The weight window generator calculates the importance values for subsections. These importance values are problem-dependent (that is, the importance values vary with system geometry and materials, as well as source characteristics, and most importantly the dose rate locations).

MCNP6 input and weight window files are submitted separately

5.4.2.2 Output Data

The MCNP6 output data includes dose rates per starting source photon (mrem/hour-photon) at specified locations and their relative errors. The relative error forms confidence intervals about the calculated dose rate. For cell tallies, a relative error less than 10% is required to produce generally reliable confidence intervals. All tallies in every MCNP6 output pass the 10 statistical checks required by MCNP6 for reliable dose rate estimations.

MCNP6 output files are submitted separately

5.4.3 Flux-to-Dose-Rate Conversion

The dose rate is determined by using flux-to-dose-rate conversion factors, which convert the tally cell flux (particles/cm^2) to the dose rate (mrem/hr). Conversion factors from *ANSI/ANS-6.1.1 1977* (Reference **[5.5]**) are used to obtain the gamma-ray dose rate. The conversion is implemented in MCNP6 by dose rate energy and dose rate function cards (Reference **[5.3]**). The calculated dose rates are normalized values per starting source particle. By also using the tally multiplier card, all tally results are multiplied by 3.7E10 so that the results are normalized per the isotope's curie level. (Refer to Equation 5-5.)

The tally cells are used to obtain the particle flux at the dose calculation points. The tally cell units are in particles per square centimeter. In this analysis, gamma rays are the particles of interest. The particle flux calculated at the dose rate locations can then be used to calculate the limiting curie content that maintains all dose rate values below the regulated values, at all surfaces.

5.4.4 External Radiation Levels

The bounding limit for an isotope is found by determining the curie level that, if any greater, would just exceed the regulatory limits at any one of the regulatory dose rate locations. A margin was added to the final dose rate limits to provide additional assurance that the regulatory dose rate limits will not be exceeded. For this additional margin, the final values were calculated to only 90% of the regulatory dose rate limits:

- 200 mrem/hr limit at the external surface became a 180 mrem/hr limit
- 1m from the external surface for Normal conditions of transport limit became a 9 mrem/hr limit
- 1m from the cask surface for Hypothetical Accident conditions of transport limit became a 900 mrem/hr limit

This methodology provides additional margin to ensure that the cask contents do not exceed the regulatory dose rate limits.

The maximum allowable curie level for each isotope is calculated using Equations 5-3, 5-4, and 5-5. First, the MCNP6 output [$Tally_{out}$] for each isotope and dose rate location is converted to units of mrem/hr-Ci, using Equation 5-3.

$$\text{Dose}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{Ci}}\right] = \text{Tally}_{\text{out}}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{photon}}\right] * \left[\frac{\text{photons}}{\text{Bq}}\right] * 3.7\text{E}10\left[\frac{\text{Bq}}{\text{Ci}}\right] \tag{5-3}$$

To provide assurance that the statistically calculated dose rate bounds the true dose rate, the calculated dose rate is increased by two times the error (2σ) to this term, as is done in Equation 5-4.

$$\text{Dose}_{+2sig}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{Ci}}\right] = \text{Dose}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{Ci}}\right] + \text{Dose}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{Ci}}\right] * 2\sigma \tag{5-4}$$

The maximum source strength that will meet the regulatory dose rate limit at the location being analyzed is then calculated using Equation 5-5.

$$\text{Source}_{\text{Max}}[\text{Ci}] = \frac{0.9 * \text{Dose}_{\text{Limit}}\left[\frac{\text{mrem}}{\text{hr}}\right]}{\text{Dose}_{+2sig}\left[\frac{\frac{\text{mrem}}{\text{hr}}}{\text{Ci}}\right]} \tag{5-5}$$

For shipments of Ir-192, there is a strong possibility that there will be Ir-194 impurities included in the source. For this case, the total dose rate is calculated as the summed dose rate contributions from the activities of both Ir-192 and Ir-194, as shown in Equation 5-6.

$$0.9 * \mathrm{Dose}_{\mathrm{Total}}\left[\frac{\mathrm{mrem}}{\mathrm{hr}}\right] = \mathrm{Dose}^{192}_{+2\mathrm{sig}}\left[\frac{\frac{\mathrm{mrem}}{\mathrm{hr}}}{\mathrm{Ci}}\right] * A^{192}[\mathrm{Ci}] + \mathrm{Dose}^{194}_{+2\mathrm{sig}}\left[\frac{\frac{\mathrm{mrem}}{\mathrm{hr}}}{\mathrm{Ci}}\right] * A^{194}[\mathrm{Ci}]$$

(5-6)

The maximum allowable source strength of Ir-192 is calculated for multiple Ir-194 impurity levels by selecting an Ir-194 activity, A^{194}, and solving Equation 5-6 for A^{192}, as shown in Equation 5-7.

$$A^{192}[\mathrm{Ci}] = \frac{0.9 * \mathrm{Dose}_{\mathrm{Total}}\left[\frac{\mathrm{mrem}}{\mathrm{hr}}\right] - \mathrm{Dose}^{194}_{+2\mathrm{sig}}\left[\frac{\frac{\mathrm{mrem}}{\mathrm{hr}}}{\mathrm{Ci}}\right] * A^{194}[\mathrm{Ci}]}{\mathrm{Dose}^{192}_{+2\mathrm{sig}}\left[\frac{\frac{\mathrm{mrem}}{\mathrm{hr}}}{\mathrm{Ci}}\right]}$$

(5-7)

The maximum curie content of each isotope at each dose rate location is solved for using the approaches outlined above. Results are then tabulated, and the minimum of the source values obtained is reported as the maximum source strength viable for shipment based on dose rate limits. The dose rates based on these source values for locations of interest are reported in Table 5-13 through Table 5-20.

A single model (identical geometry and source specifications) is used for both Normal conditions and Hypothetical Accident conditions of transport simulations. The dose rates reported are applicable to both scenarios.

The following dose rate limits are met for all isotopes, in compliance with *10 CFR 71.47(a)* and *71.51(a)(2)* (Reference **[5.1]**; Normal conditions and Hypothetical Accident conditions of transport, respectively):

- Surface limit of 200 mrem/hr (2mSv/h) on the impact limiter's external surface to comply with Normal conditions of transport limits
- Limit of 1,000 mrem/hr (10 mSv/h) at 1m from the cask surface to comply with Hypothetical Accident conditions of transport limits
- Limit of 10 mrem/hr at 1m from the shipping cage to comply with Normal conditions of transport limits

For the activity limits of all individual isotopes, refer to Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models." For the activity limits of Ir-192 sources with Ir-194 impurities, refer to Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models."

Shipment Transportation Index (TI) can be calculated by using the highest dose at 1m from the deformed impact limiter for each isotope and transport package combination. These numbers are defined in Table 5-13 through Table 5-20. The dose rates reported result in a single package always having a TI less than 10, allowing for non-exclusive shipment of a single cask. If multiple casks are shipped together, their respective TI values must be summed to determine whether their shipment must be for exclusive or non-exclusive use.

Table 5-13. Maximum Radiation Levels (All Isotopes Except Ir-192 and Ir-194)[a] – Model AOS-025A

Isotope	Source Strength (Ci)	Photon/Bq	Location	Maximum Dose Rate/ Curie (mrem/hr/ Ci)	Peak Dose Rate (mrem/hr)	Limit (mrem/hr)	Shipping Configuration
Co-60	1.33E-01	1.9986	External Surface	1.355E+03	180.00	200	Use of Tungsten Alloy Liner (183C8485) is required
			1m from Cask Surface	1.879E+01	2.50	1,000	
			1m from External Surface	1.713E+01	2.28	10	
Cs-137	1.00E+01	0.9811	External Surface	1.800E+01	180.00	200	
			1m from Cask Surface	3.252E-01	3.25	1,000	
			1m from External Surface	2.835E-01	2.83	10	
Ho-166	1.32E+01	0.20611	External Surface	1.366E+01	180.00	200	
			1m from Cask Surface	1.906E-01	2.51	1,000	
			1m from External Surface	1.736E-01	2.29	10	
Yb-169	1.59E+05	3.7623	External Surface	1.131E-03	180.00	200	
			1m from Cask Surface	2.307E-05	3.67	1,000	
			1m from External Surface	1.995E-05	3.18	10	

a. *Refer to Table 5-17 for Ir-192 and Ir-194 maximum radiation levels.*

Table 5-14. Maximum Radiation Levels (All Isotopes Except Ir-192 and Ir-194)[a]– Model AOS-050A

Isotope	Source Strength (Ci)	Photon/Bq	Location	Maximum Dose Rate/ Curie (mrem/hr/ Ci)	Peak Dose Rate (mrem/hr)	Limit (mrem/hr)	Shipping Configuration
Co-60	7.50E-01	1.9986	External Surface	2.400E+02	180.00	200	No Additional Components
			1m from Cask Surface	1.178E+01	8.84	1,000	
			1m from External Surface	8.837E+00	6.63	10	
Cs-137	1.93E+01	0.9811	External Surface	9.345E+00	180.00	200	
			1m from Cask Surface	3.926E-01	7.56	1,000	
			1m from External Surface	2.933E-01	5.65	10	
Hf-181	9.23E+01	1.8501	External Surface	1.951E+00	180.00	200	
			1m from Cask Surface	7.598E-02	7.01	1,000	
			1m from External Surface	5.774E-02	5.33	10	
Zr/Nb-95	2.90E+00	3.2000	External Surface	6.204E+01	180.00	200	
			1m from Cask Surface	2.755E+00	7.99	1,000	
			1m from External Surface	2.068E+00	6.00	10	
Ho-166	7.59E+01	0.2061	External Surface	2.372E+00	180.00	200	
			1m from Cask Surface	1.191E-01	9.03	1,000	
			1m from External Surface	8.938E-02	6.78	10	
Yb-169	9.44E+03	3.7623	External Surface	1.907E-02	180.00	200	
			1m from Cask Surface	7.277E-04	6.87	1,000	
			1m from External Surface	5.804E-04	5.48	10	

a. Refer to Table 5-18 for Ir-192 and Ir-194 maximum radiation levels.

Table 5-15. Maximum Radiation Levels (All Isotopes Except Ir-192 and Ir-194)[a] – Model AOS-100A and AOS-100A-S

Isotope	Source Strength (Ci)	Photon/Bq	Location	Maximum Dose Rate/ Curie (mrem/hr/ Ci)	Peak Dose Rate (mrem/hr)	Limit (mrem/hr)	Shipping Configuration
Co-60	2.73E+02	1.9986	External Surface	3.912E-01	106.95	200	No Liner
			1m from Cask Surface	5.545E-02	15.16	1,000	
			1m from External Surface	3.292E-02	9.00	10	
Co-60-B	8.23E+02	1.9986	External Surface	1.139E-01	93.77	200	Use of Tungsten Alloy Axial Shielding Plates (183C8491) is required
			1m from Cask Surface	1.833E-02	15.09	1,000	
			1m from External Surface	1.093E-02	9.00	10	
Co-60-C[b]	2.02E+04	1.9986	External Surface	3.974E-03	79.80	200	Use of Tungsten Alloy Axial Shielding Plates (183C8491) and Cavity Spacer Plates (183C8518) are required
			1m from Cask Surface[c]	1.833E-02	370.27	1,000	
			1m from External Surface	4.452E-04	9.00	10	
Cs-137	3.55E+04	0.9811	External Surface	3.188E-03	113.31	200	–
			1m from Cask Surface	4.152E-04	14.76	1,000	
			1m from External Surface	2.532E-04	9.00	10	
Hf-181	4.34E+05	1.8501	External Surface	2.595E-04	112.50	200	
			1m from Cask Surface	3.413E-05	14.80	1,000	
			1m from External Surface	2.076E-05	9.00	10	
Zr/Nb-95	3.61E+03	3.2000	External Surface	3.098E-02	111.80	200	
			1m from Cask Surface	4.106E-03	14.82	1,000	
			1m from External Surface	2.494E-03	9.00	10	

a. *Refer to Table 5-17 for Ir-192 and Ir-194 maximum radiation levels.*

b. *For Co-60-C quantities, the maximum allowable specific activity is 350 Ci/g (that is, no more than 350 Ci of Co-60 in a gram of Cobalt).*

c. *Dose rates based on Co-60-B configuration, assuming that only the tungsten alloy axial shielding plates survive Hypothetical Accident conditions of transport.*

Table 5-16. Maximum Radiation Levels (All Isotopes Except Ir-192 and Ir-194)[a] – Model AOS-100B

Isotope	Source Strength (Ci)	Photon/Bq	Location	Maximum Dose Rate/ Curie (mrem/hr/ Ci)	Peak Dose Rate (mrem/hr)	Limit (mrem/hr)	Shipping Configuration
Co-60	1.09E+01	1.9986	External Surface	9.217E+00	100.29	200	No Additional Components
			1m from Cask Surface	1.358E+00	14.77	1,000	
			1m from External Surface	8.271E-01	9.00	10	
Cs-137	5.82E+02	0.9811	External Surface	1.871E-01	108.84	200	
			1m from Cask Surface	2.515E-02	14.63	1,000	
			1m from External Surface	1.547E-02	9.00	10	
Hf-181	4.39E+03	1.8501	External Surface	2.527E-02	110.93	200	
			1m from Cask Surface	3.354E-03	14.72	1,000	
			1m from External Surface	2.051E-03	9.00	10	
Zr/Nb-95	7.31E+01	3.2000	External Surface	1.459E+00	106.60	200	
			1m from Cask Surface	2.000E-01	14.62	1,000	
			1m from External Surface	1.232E-01	9.00	10	

a. *Refer to Table 5-17 for Ir-192 and Ir-194 maximum radiation levels.*

Table 5-17. Maximum Ir-192/Ir-194 Radiation Levels – Model AOS-025A

A_{194} (Ci)	A_{192} (Ci)	Location	DR_{194} (mrem/hr/Ci)	DR_{192} (mrem/hr/Ci)	Total Dose Rate (mrem/hr)	Limit (mrem/hr)	Total Thermal Power (W)	Shipping Configuration
0.5	71.52	External Surface	1.367E+01	2.421E+00	180.00	200	0.44	Use of Tungsten Alloy Liner 183C8485 is required
		1m from Cask Surface	1.920E-01	4.875E-02	3.58	1,000		
		1m from External Surface	1.734E-01	4.259E-02	3.13	10		
2.0	63.04	External Surface	1.367E+01	2.421E+00	180.00	200	0.40	
		1m from Cask Surface	1.920E-01	4.875E-02	3.46	1,000		
		1m from External Surface	1.734E-01	4.259E-02	3.03	10		
3.0	57.40	External Surface	1.367E+01	2.421E+00	180.00	200	0.37	
		1m from Cask Surface	1.920E-01	4.875E-02	3.37	1,000		
		1m from External Surface	1.734E-01	4.259E-02	2.96	10		

Table 5-18. Maximum Ir-192/Ir-194 Radiation Levels – Model AOS-050A

A_{194} (Ci)	A_{192} (Ci)	Location	DR_{194} (mrem/hr/Ci)	DR_{192} (mrem/hr/Ci)	Total Dose Rate (mrem/hr)	Limit (mrem/hr)	Total Thermal Power (W)	Shipping Configuration
10	1,117	External Surface	6.213E-01	1.555E-01	180.00	200	6.90	Use of Axial Shielding Plates 183C8519 is required
		1m from Cask Surface[a]	1.334E-01	1.042E-01	117.73	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.29	10		
20	1,077	External Surface	6.213E-01	1.555E-01	180.00	200	6.71	
		1m from Cask Surface[a]	1.334E-01	1.042E-01	114.89	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.30	10		
40	997	External Surface	6.213E-01	1.555E-01	180.00	200	6.33	
		1m from Cask Surface[a]	1.334E-01	1.042E-01	109.22	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.32	10		
60	917	External Surface	6.213E-01	1.555E-01	180.00	200	5.94	
		1m from Cask Surface[a]	1.334E-01	1.042E-01	103.56	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.35	10		
80	837	External Surface	6.213E-01	1.555E-01	180.00	200	5.56	
		1m from Cask Surface[a]	1.334E-01	1.042E-01	97.89	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.37	10		
100	758	External Surface	6.213E-01	1.555E-01	180.00	200	5.18	
		1m from Cask Surface[a]	1.334E-01	1.042E-01	92.32	1,000		
		1m from External Surface	2.628E-02	6.286E-03	7.39	10		

a. *Dose rates calculated excluding stainless steel axial shielding plates, assuming that they do not survive Hypothetical Accident conditions of transport.*

Table 5-19. Maximum Ir-192/Ir-194 Radiation Levels – Model AOS-100A and AOS-100A-S

A_{194} (Ci)	A_{192} (Ci)	Location	DR_{194} (mrem/hr/Ci)	DR_{192} (mrem/hr/Ci)	Total Dose Rate (mrem/hr)	Limit (mrem/hr)	Total Thermal Power (W)	Shipping Configuration
4,000	61,794.45	External Surface	4.502E-03	5.802E-04	53.86	200	400.00	No additional shielding is required
		1m from Cask Surface	6.536E-04	7.547E-05	7.28	1,000		
		1m from External Surface	3.871E-04	4.619E-05	4.40	10		
10,000	56,606.85	External Surface	4.502E-03	5.802E-04	77.86	200	400.00	
		1m from Cask Surface	6.536E-04	7.547E-05	10.81	1,000		
		1m from External Surface	3.871E-04	4.619E-05	6.49	10		

Table 5-20. Maximum Ir-192/Ir-194 Radiation Levels – Model AOS-100B

A_{194} (Ci)	A_{192} (Ci)	Location	DR_{194} (mrem/hr/Ci)	DR_{192} (mrem/hr/Ci)	Total Dose Rate (mrem/hr)	Limit (mrem/hr)	Total Thermal Power (W)	Shipping Configuration
100	2,414.88	External Surface	1.016E-01	4.084E-02	108.77	200	15.33	No additional shielding is required
		1m from Cask Surface	1.502E-02	5.431E-03	14.62	1,000		
		1m from External Surface	9.118E-03	3.349E-03	9.00	10		
230	2,060.99	External Surface	1.016E-01	4.084E-02	107.53	200	13.85	
		1m from Cask Surface	1.502E-02	5.431E-03	14.65	1,000		
		1m from External Surface	9.118E-03	3.349E-03	9.00	10		

5.5 APPENDIX

5.5.1 AOS Cask Isotopic Heat Load Calculations

Table 5-21 provides the decay heat values generated from SCALE 6.1 ORIGEN [5.2] decay library *origen.rev03.decay.data* for each isotope analyzed in this chapter. This library provides a Q value, in MeV/ disintegration, for each isotope. For each isotope, Table 5-21 also provides the isotope identifier and Q value in the ORIGEN decay library.

For Cs-137, it is assumed that this isotope is combined with Ba-137m (due to the short half-life of Ba-137m). As a result, the heat load for Cs-137 is calculated using the Cs-137 and Ba-137m Q-value sum.

To be consistent with the shielding evaluation supporting Zr/Nb-95, the heat load is determined by multiplying the higher Q value of the two isotopes (Zr-95 as seen in Table 5-21) by a factor of 3.2. The resulting value is 1.62E-02 W/Ci for Zr/Nb-95.

Table 5-22 summarizes the final heat load values applicable to the isotopes analyzed in this chapter. These values, along with the respective cask decay heat limits reported in Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models," and Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models," are used to calculate activity limits based on heat loads. The heat load presented in Table 5-22 for each isotope is calculated as shown in Equation 5-8.

$$\text{Heat Load}\left[\frac{\text{W}}{\text{Ci}}\right] = \text{Q}\left[\frac{\text{MeV}}{\text{disintegration}}\right] * 1.60217 * 10^{-13}\left[\frac{\text{J}}{\text{MeV}}\right] * 3.7 * 10^{10}\left[\frac{\frac{\text{disintegrations}}{\text{s}}}{\text{Ci}}\right] \tag{5-8}$$

Table 5-21. AOS Cask Isotopic Heat Loads (Reference [5.2])

Isotope	Library Isotope Identifier *(origen.rev03.decay.data)*	Q Value (MeV/disintegration)
Co-60	270600	2.6006E+00
Cs-137	551370	1.7945E-01
Ba-137m	561371	6.6140E-01
Hf-181	721810	7.3010E-01
Ir-192	771920	1.0334E+00
Ir-194	771940	8.9387E-01
Zr-95	400950	8.5013E-01
Nb-95	410950	8.0900E-01
Ho-166	671660	7.2354E-01
Yb-169	701690	4.3013E-01

Table 5-22. AOS Cask Isotopic Heat Load Results

Isotope	Heat Load (W/Ci)
Co-60	1.55E-02
Cs-137	4.99E-03
Hf-181	4.33E-03
Ir-192	6.13E-03
Ir-194	5.30E-03
Zr/Nb-95	1.62E-02
Ho-166	4.29E-03
Yb-169	2.55E-03

5.5.2 Isotope Values for Calculations

Table 5-23. Isotope Photon per Decay – All Models

Isotope	Photons/Decay	Model		
		AOS-025	AOS-050	AOS-100
Co-60	1.9986	✔	✔	✔
Cs-137	0.9811	✔	✔	✔
Hf-181	1.8501		✔	✔
Ir-192	2.3591	✔	✔	✔
Ir-194	0.2141	✔	✔	✔
Zr/Nb-95	3.2000		✔	✔
Ho-166	0.2061	✔	✔	
Yb-169	3.7623	✔	✔	

Table 5-24. Co-60 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
7.5100E-04	1.6946E-06	✔	✔	✔
8.5234E-04	8.0550E-07			
8.7689E-04	1.3826E-08			
8.8364E-04	5.6638E-07			
7.4178E-03	3.1894E-05			
7.4358E-03	6.2286E-05			
8.2223E-03	3.9005E-06			
8.2246E-03	7.6481E-06			
8.2879E-03	3.3435E-09			
8.2881E-03	4.8594E-09			
3.4714E-01	7.5000E-05			
8.2610E-01	7.6000E-05			
1.1732E+00	9.9850E-01			
1.3325E+00	9.9983E-01			
2.1586E+00	1.2000E-05			
2.5057E+00	2.0000E-08			

Table 5-25. Cs-137 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
4.4700E-03	9.6595E-03	✔	✔	✔
3.1817E-02	2.1043E-02			
3.2194E-02	3.8387E-02			
3.6304E-02	3.6743E-03			
3.6378E-02	7.0939E-03			
3.7255E-02	2.2441E-03			
6.6166E-01	8.9900E-01			

Table 5-26. Hf-181 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
7.5803E-03	3.1170E-03	✔	✔	✔
8.1315E-03	3.7431E-02			
9.4239E-03	3.0249E-02			
1.0926E-02	4.5632E-03			
5.6402E-02	9.0128E-02			
5.7686E-02	1.5707E-01			
6.5104E-02	1.6811E-02			
6.5381E-02	3.2483E-02			
6.5763E-02	3.5211E-04			
6.5823E-02	4.4618E-04			
6.7104E-02	3.8016E-03			
6.7168E-02	7.3649E-03			
6.7323E-02	8.3999E-05			
6.7334E-02	1.0591E-04			
6.3000E-03	1.1511E-04			
1.3302E-01	4.3309E-01			
1.3626E-01	5.8523E-02			
1.3686E-01	8.6135E-03			
3.4593E-01	1.5118E-01			
4.7599E-01	7.0276E-03			
4.8218E-01	8.0500E-01			
6.1517E-01	2.3345E-03			
6.1866E-01	2.5035E-04			

Table 5-27. Ir-192 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
8.3025E-03	6.6719E-04	✔	✔	✔
8.8986E-03	7.6141E-03			
9.0571E-03	1.8748E-03			
9.4295E-03	1.9970E-02			
1.0425E-02	6.3780E-03			
1.1127E-02	1.8272E-02			
1.2198E-02	1.0622E-03			
1.3025E-02	3.1858E-03			
6.1642E-02	1.2211E-02			
6.3189E-02	2.1041E-02			
6.5302E-02	2.6539E-02			
6.7048E-02	4.5551E-02			
7.1276E-02	2.2846E-03			
7.1614E-02	4.4158E-03			
7.2021E-02	5.2499E-05			
7.2095E-02	6.5560E-05			
7.3520E-02	5.2604E-04			
7.3600E-02	1.0228E-03			
7.3769E-02	1.3000E-05			
7.3784E-02	1.6170E-05			
7.5593E-02	5.0098E-03			
7.5978E-02	9.6917E-03			
7.6403E-02	1.2217E-04			
7.6486E-02	1.5101E-04			
7.8011E-02	1.1680E-03			
7.8103E-02	2.2787E-03			
7.8282E-02	3.1008E-05			
7.8299E-02	3.8202E-05			
1.1040E-01	1.2200E-04			
1.3634E-01	1.9900E-03			
1.7698E-01	4.3000E-05			
2.0131E-01	4.7300E-03			
2.0579E-01	3.3400E-02			
2.8027E-01	9.0001E-05			

Table 5-27. Ir-192 Gamma Spectra Used in Shielding Models – All Models (Continued)

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
2.8327E-01	2.6600E-03	✔	✔	✔
2.9596E-01	2.8720E-01			
3.0846E-01	2.9680E-01			
3.1651E-01	8.2711E-01			
3.2917E-01	1.7400E-04			
3.7449E-01	7.2600E-03			
4.1647E-01	6.6900E-03			
4.2052E-01	6.9000E-04			
4.6807E-01	4.7810E-01			
4.8458E-01	3.1870E-02			
4.8530E-01	2.3000E-05			
4.8906E-01	4.3800E-03			
5.8858E-01	4.5170E-02			
5.9349E-01	4.2100E-04			
5.9941E-01	3.9000E-05			
6.0441E-01	8.2001E-02			
6.1246E-01	5.3400E-02			
7.0387E-01	5.3000E-05			
7.6580E-01	1.3000E-05			
8.8454E-01	2.9100E-03			
1.0615E+00	5.3000E-04			
1.0899E+00	1.2000E-05			
1.3782E+00	1.2000E-05			

Table 5-28. Ir-194 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
9.0557E-03	1.7306E-04	✔	✔	✔
9.4295E-03	1.8464E-03			
1.1127E-02	1.6826E-03			
1.3024E-02	2.9287E-04			
6.5302E-02	2.5064E-03			
6.7048E-02	4.2842E-03			
7.5593E-02	4.6947E-04			
7.5978E-02	9.0788E-04			
7.6403E-02	1.1443E-05			
7.6486E-02	1.4144E-05			
7.8011E-02	1.0940E-04			
7.8103E-02	2.1343E-04			
7.8282E-02	2.9043E-06			
7.8299E-02	3.5780E-06			
1.1140E-01	1.7030E-05			
2.0291E-01	3.0130E-05			
2.4483E-01	7.7290E-05			
2.9354E-01	2.5152E-02			
3.0074E-01	3.4846E-03			
3.2845E-01	1.3100E-01			
3.6487E-01	4.1134E-04			
4.8286E-01	4.5588E-04			
5.3017E-01	1.5851E-04			
5.8918E-01	1.4017E-03			
5.9429E-01	6.2487E-04			
6.0761E-01	3.9300E-05			
6.2129E-01	9.5630E-05			
6.2197E-01	3.3405E-03			
6.4515E-01	1.1751E-02			
6.9950E-01	2.4890E-05			
7.0055E-01	2.6200E-04			
8.1066E-01	2.4890E-05			
8.5712E-01	7.0740E-05			
8.5945E-01	1.7030E-05			

Table 5-28. Ir-194 Gamma Spectra Used in Shielding Models – All Models (Continued)

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
8.8998E-01	5.0566E-04	✔	✔	✔
9.2526E-01	1.2576E-04			
9.3869E-01	5.9867E-03			
1.0001E+00	4.6505E-04			
1.0486E+00	2.6069E-04			
1.1041E+00	2.6069E-04			
1.1508E+00	6.0129E-03			
1.1566E+00	1.8340E-05			
1.1754E+00	6.0522E-04			
1.1835E+00	3.0654E-03			
1.1864E+00	8.3840E-05			
1.2188E+00	5.6330E-04			
1.2937E+00	4.5981E-04			
1.3082E+00	1.2969E-05			
1.3422E+00	3.7990E-04			
1.4215E+00	6.2880E-06			
1.4314E+00	2.2270E-05			
1.4325E+00	1.1397E-05			
1.4418E+00	1.4934E-05			
1.4502E+00	1.6375E-05			
1.4635E+00	5.8950E-05			
1.4689E+00	1.9257E-03			
1.4870E+00	1.7030E-04			
1.4922E+00	1.4541E-05			
1.5120E+00	2.3580E-04			
1.5122E+00	1.3231E-04			
1.5188E+00	1.6637E-05			
1.5652E+00	2.0829E-04			
1.5958E+00	1.6244E-05			
1.6019E+00	1.9519E-05			
1.6222E+00	6.4190E-04			
1.6707E+00	5.7640E-05			
1.7153E+00	1.3100E-05			
1.7245E+00	7.5980E-06			

Table 5-28. Ir-194 Gamma Spectra Used in Shielding Models – All Models (Continued)

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
1.7354E+00	2.4890E-05	✔	✔	✔
1.7573E+00	4.1920E-06			
1.7807E+00	5.2400E-05			
1.7857E+00	4.0217E-05			
1.7975E+00	1.7554E-04			
1.8058E+00	3.2488E-04			
1.8126E+00	4.4540E-06			
1.8296E+00	1.9257E-05			
1.9244E+00	1.8340E-05			
2.0437E+00	7.0740E-05			
2.1142E+00	2.6069E-05			

Table 5-29. Zr/Nb-95 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
7.6600E-01	3.2000E+00		✔	✔

Table 5-30. Ho-166 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
6.3618E-03	9.0722E-04	✔	✔	
6.9310E-03	1.0365E-02			
7.8984E-03	8.2584E-03			
9.1036E-03	1.1969E-03			
4.8299E-02	3.0487E-02			
4.9227E-02	5.4100E-02			
5.5582E-02	5.6350E-03			
5.5778E-02	1.0891E-02			
5.6119E-02	9.9792E-05			
5.6162E-02	1.2934E-04			
5.7217E-02	1.2475E-03			
5.7261E-02	2.4141E-03			
5.7394E-02	2.2772E-05			
5.7402E-02	2.9377E-05			
8.0574E-02	6.7100E-02			
1.8440E-01	2.0000E-05			
5.2080E-01	3.3000E-06			
6.7400E-01	1.9400E-04			
7.0530E-01	1.3100E-04			
7.8589E-01	1.1900E-04			
1.2631E+00	1.4000E-05			
1.3794E+00	9.3000E-03			
1.4476E+00	9.8000E-06			
1.5282E+00	2.0000E-06			
1.5819E+00	1.8700E-03			
1.6625E+00	1.2000E-03			
1.7499E+00	2.7700E-04			
1.8305E+00	8.5000E-05			

Table 5-31. Yb-169 Gamma Spectra Used in Shielding Models – All Models

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
6.4053E-03	1.8357E-02	✔	✔	
7.1637E-03	2.1264E-01			
8.1831E-03	1.8668E-01			
9.5498E-03	2.9349E-02			
4.9859E-02	5.2762E-01			
5.0850E-02	9.3274E-01			
5.7413E-02	9.7740E-02			
5.7623E-02	1.8890E-01			
5.7972E-02	1.7927E-03			
5.8018E-02	2.3136E-03			
5.9117E-02	2.1696E-02			
5.9164E-02	4.1962E-02			
5.9301E-02	4.1114E-04			
5.9310E-02	5.2762E-04			
8.4102E-03	3.5930E-03			
2.0752E-02	1.9797E-03			
4.2760E-02	1.2575E-03			
4.5940E-02	5.3895E-05			
5.0610E-02	2.6947E-03			
5.0860E-02	2.6947E-03			
5.1510E-02	8.9825E-05			
6.3010E-02	1.0779E-02			
6.3120E-02	4.3619E-01			
6.5860E-02	5.2099E-05			
7.2028E-02	1.7965E-05			
8.5090E-02	1.4372E-05			
9.3614E-02	2.5798E-02			
9.5700E-02	1.0779E-05			
9.5850E-02	1.0779E-05			
9.8010E-02	8.9825E-06			
1.0141E-01	3.5930E-05			
1.0519E-01	2.5870E-05			
1.0978E-01	1.7387E-01			
1.1362E-01	5.3895E-05			

Table 5-31. Yb-169 Gamma Spectra Used in Shielding Models – All Models (Continued)

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
1.1398E-01	4.3116E-05	✔	✔	
1.1738E-01	3.9882E-04			
1.1819E-01	1.8741E-02			
1.2994E-01	2.6947E-03			
1.3052E-01	1.1383E-01			
1.5672E-01	9.8807E-05			
1.7388E-01	1.4372E-05			
1.7721E-01	2.2280E-01			
1.9315E-01	7.5453E-05			
1.9796E-01	3.5930E-01			
1.9977E-01	1.6169E-04			
2.0599E-01	3.3774E-05			
2.1394E-01	2.9103E-05			
2.2630E-01	2.5151E-06			
2.2871E-01	1.9762E-06			
2.4033E-01	1.1390E-03			
2.6108E-01	1.6794E-02			
2.9119E-01	4.3116E-05			
2.9454E-01	9.7011E-06			
3.0173E-01	2.3354E-05			
3.0683E-01	8.9825E-04			
3.0752E-01	2.5151E-03			
3.0774E-01	1.0046E-01			
3.3396E-01	1.7426E-05			
3.3662E-01	9.4496E-05			
3.5674E-01	1.4085E-06			
3.7085E-01	8.8029E-06			
3.7928E-01	4.0601E-06			
3.8667E-01	3.3487E-06			
4.5262E-01	1.7606E-07			
4.6470E-01	3.5930E-08			
4.6565E-01	1.9043E-06			
4.6670E-01	1.9402E-07			
4.7497E-01	1.9438E-06			

Table 5-31. Yb-169 Gamma Spectra Used in Shielding Models – All Models (Continued)

Energy (MeV)	Absolute Probability of Emission per Decay	Model		
		AOS-025	AOS-050	AOS-100
4.9436E-01	1.4731E-05	✔	✔	
5.0035E-01	8.8388E-08			
5.0780E-01	1.4731E-08			
5.1510E-01	4.1715E-05			
5.2857E-01	1.1965E-06			
5.4616E-01	1.4731E-08			
5.6241E-01	1.1893E-06			
5.7089E-01	1.1138E-06			
5.7985E-01	1.9258E-05			
6.0060E-01	1.1390E-05			
6.2488E-01	4.9224E-05			
6.3332E-01	6.8986E-08			
6.4287E-01	7.6531E-07			
6.6360E-01	1.9330E-06			
6.9346E-01	8.6951E-08			
7.1035E-01	3.4134E-07			
7.3942E-01	1.8324E-08			
7.6024E-01	8.2639E-09			
7.7339E-01	2.0875E-06			
7.8164E-01	3.0181E-08			

5.5.3 MCNP6 Input and Output Files for Dose Calculations

Submitted separately.

5.5.4 Cobalt-60-C Volume Source Calculation

For the Model AOS-100A/AOS-100A-S casks, the Co-60-C configuration considers a volume source for the dose rate calculations. The first step for using a bounding volume source is to determine a minimum volume that the source will occupy. For Co-60, there is a practical specific activity limit of 350 Ci/g, meaning that the maximum activity that any single gram of Cobalt may contain is 350 Ci. This 350 Ci/g limit is used to determine the minimum volume that a given activity of cobalt will occupy. Any reduction in the specific activity would result in a larger volume of Cobalt. At a specific activity of 350 Ci/g, the desired activity limit of at least 19,000 Ci Co-60 would result in a minimum mass of 54.29g of Cobalt. With a density of 8.9g/cm^3, this mass of Cobalt takes up a volume of 6.1 cm^3. So, at a specific activity of 350 Ci/g or less, any activity of Co-60 greater than or equal to 19,000 Ci will occupy a volume of at least 6.1 cm^3. As long as the calculated minimum activity is greater than 19,000 Ci, a volume of 6.1 cm^3 is bounding because a greater activity will only result in a larger volume.

In addition to determining the minimum volume that the source will occupy, it must be determined what geometry distribution of this volume would result in the highest dose rate. To make this determination, it is considered that the sources will either accumulate into one of two geometries – either a lumped **cylinder** or an **arc segment** within the cask's top corner. Figure 5-8 illustrates these two geometries, as follows:

- **Transparent blue cell** – Usable cask cavity
- **Solid blue and yellow cells** – Axial shielding plates
- **Solid green cell** – Source volume

Table 5-32 lists the variations of the cylinder and arc segment geometries to determine the most limiting geometry of each. Table 5-33 lists the results for this analysis. Because the arc segment geometry with r_i = 6.0 cm and θ = 80° results in the most restrictive activity limit, the dose rate results from this case are used for the Co-60-C isotope for the Model AOS-100A/AOS-100A-S casks.

Table 5-32. Volume Source Analysis – Source Geometry Dimensions

Geometry	Case		h (cm)	r[a] (cm)	θ (°)	V (cm^3)
Cylinder	H = D		1.98	0.99	360	6.1
	H = 2D		3.15	0.785	360	6.1
	2H = D		1.25	1.245	360	6.1
Arc Segment	ID = 5.75 in.	θ = 80°	0.5936	7.3025	80	6.1
	ID = 5.75 in.	θ = 90°	0.5276	7.3025	90	6.1
	ID = 5.75 in.	θ = 100°	0.4748	7.3025	100	6.1
	ID = 6.00 in.	θ = 80°	0.8753	7.6200	80	6.1
	ID = 6.00 in.	θ = 90°	0.7781	7.6200	90	6.1
	ID = 6.00 in.	θ = 100°	0.7002	7.6200	100	6.1
	ID = 6.25 in.	θ = 80°	1.7329	7.9375	80	6.1
	ID = 6.25 in.	θ = 90°	1.5403	7.9375	90	6.1
	ID = 6.25 in.	θ = 100°	1.3863	7.9375	100	6.1

a. *For the Cylinder geometry, the radius dimension refers to the cylinder's radius.*
For the Arc Segment geometry, the radius refers to the arc's inner radius because the arc's outer radius is equal to the cask cavity's radius.

Table 5-33. Volume Source Analysis – Results

Geometry	Case	Surface Dose Rate (mrem/hr/Ci)	Transport Index 1m Dose Rate (mrem/hr/Ci)
Cylinder	H = D	3.986E-03	3.011E-04
	H = 2D	4.209E-03	3.170E-04
	2H = D	3.627E-03	2.783E-04
Arc Segment	ID = 5.75 in. θ = 80°	3.783E-03	3.997E-04
	ID = 5.75 in. θ = 90°	3.707E-03	3.941E-04
	ID = 5.75 in. θ = 100°	3.690E-03	3.912E-04
	ID = 6.00 in. θ = 80°	3.947E-03	4.452E-04
	ID = 6.00 in. θ = 90°	3.999E-03	4.379E-04
	ID = 6.00 in. θ = 100°	3.996E-03	4.307E-04
	ID = 6.25 in. θ = 80°	3.695E-03	3.796E-04
	ID = 6.25 in. θ = 90°	3.560E-03	3.914E-04
	ID = 6.25 in. θ = 100°	3.659E-03	4.135E-04
Maximum Dose Rate (mrem/hr/Ci)		4.209E-03	4.452E-04
Resulting A_{limit}[Ci][a]		**42,763**	**20,214**

a. *Refer to Equation 5-5.*

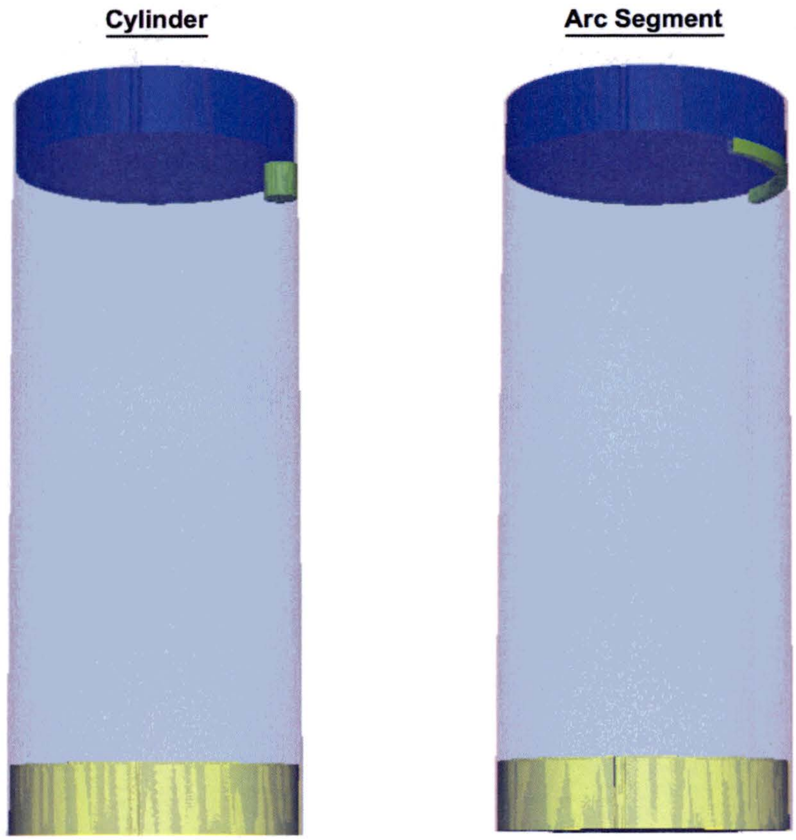

Figure 5-8. MCNP6 Volume Source Location/Geometries

5.6 REFERENCES

[5.1] U.S. Nuclear Regulatory Commission (NRC), *Title 10 Code of Federal Regulations, Part 71 (10 CFR 71)*, "Packaging and Transportation of Radioactive Material."

[5.2] Oak Ridge National Laboratory, *ORNL/TM-2005/39 Version 6.1*. "SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design," June, 2011.

[5.3] Goorley T., et al., *Initial MCNP 6 Release Overview – MCNP6 Version 1.0*, Los Alamos National Laboratory, LA-UR-13-22934, April, 2013.

[5.4] Conlin J., et al., *Listing of Available ACE Data Tables*, Los Alamos National Laboratory, LA-UR-13-21822, Rev. 4, June, 2014.

[5.5] American Nuclear Society, *ANSI/ANS-6.1.1-1977*, "Neutron and Gamma-Ray Fluence-to-Dose Factor," 1977.

[5.6] SAE International, *AMST 21014*, "Tungsten Base Metal, High Density," September 1, 1998.

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7 PACKAGE OPERATIONS

The information within this chapter provides the operations used to load the AOS Transport Packaging System and prepare it for transport. These operations describe the fundamental steps needed to ensure the requirements of this SAR. The transport packages should be operated using detailed written procedures that are based upon, and consistent with, the operations described in this chapter. During actual operation, these procedures can be supplemented with engineering personnel, training classes, and/or site-specific procedures, as applicable.

Figure 7-1 and Figure 7-2 provide isometric views of Models AOS-025A and AOS-050A, respectively. Figure 7-3 provides an isometric view of Models AOS-100A and AOS-100B. Figure 7-3a provides an isometric view of Model AOS-100A-S.

Note: *Unless indicated otherwise, all information related to the Model AOS-100A is also applicable to Models AOS-100B and AOS-100A-S.*

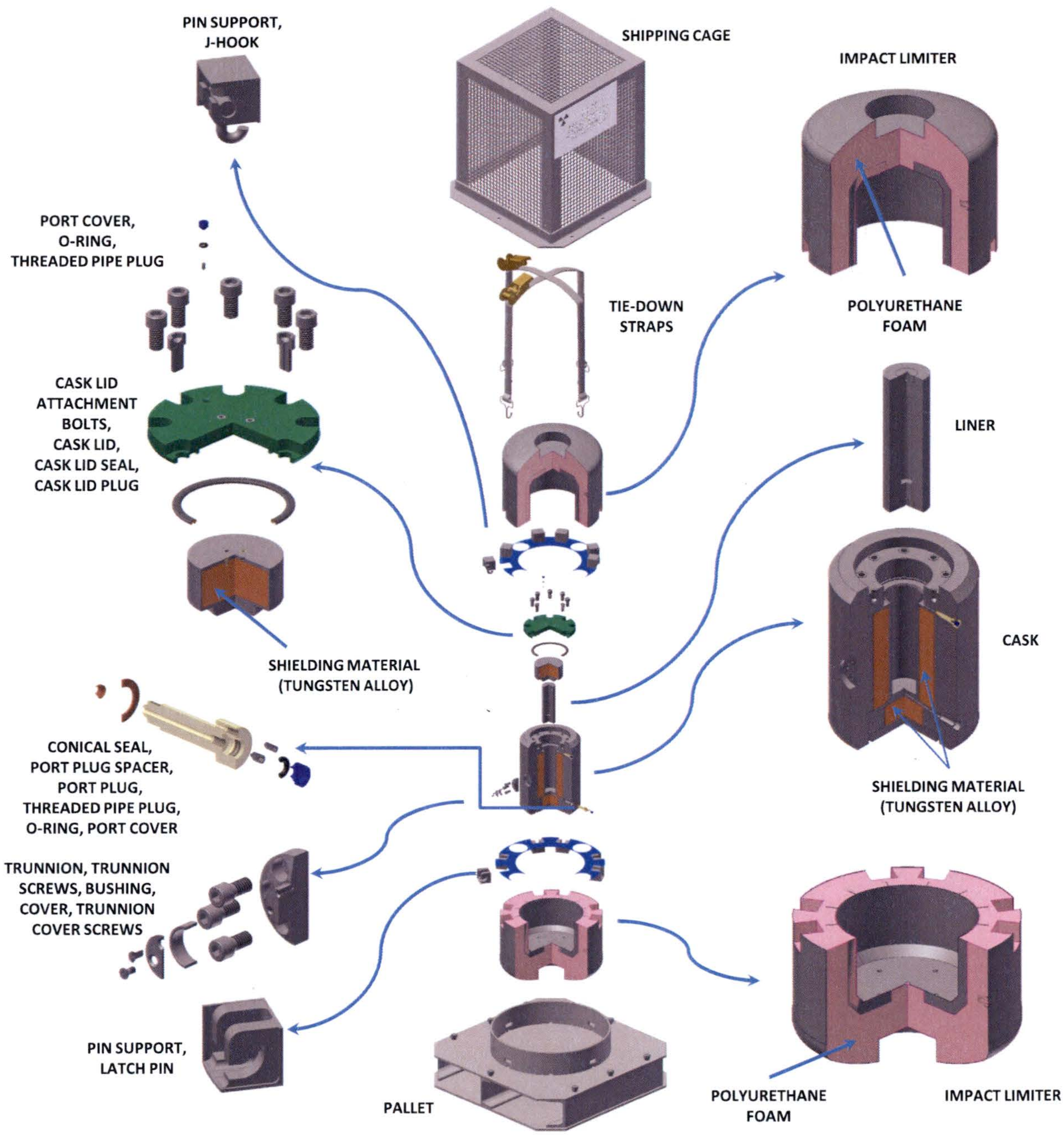

Figure 7-1. Isometric View – Model AOS-025A

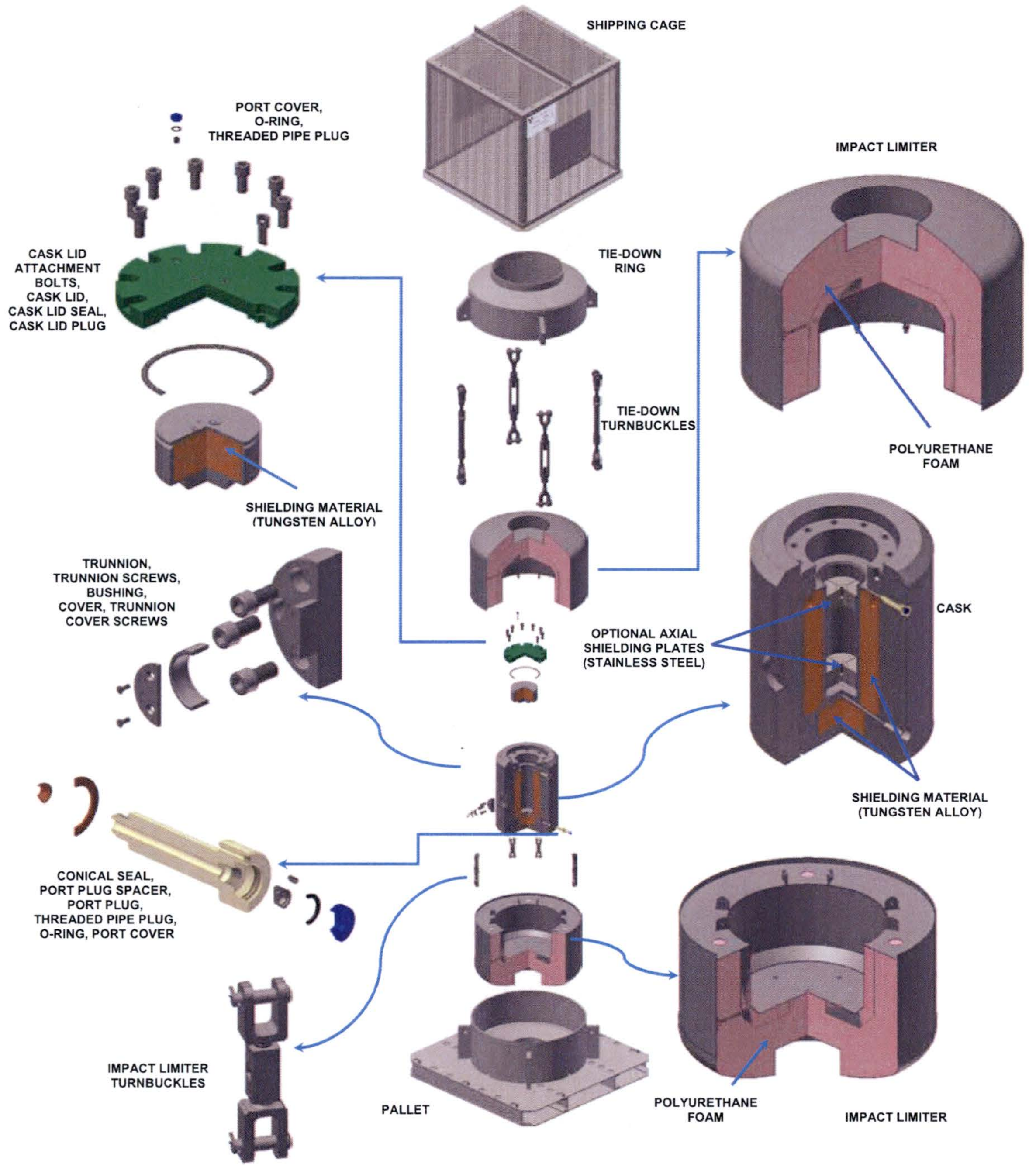

Figure 7-2. Isometric View – Model AOS-050A

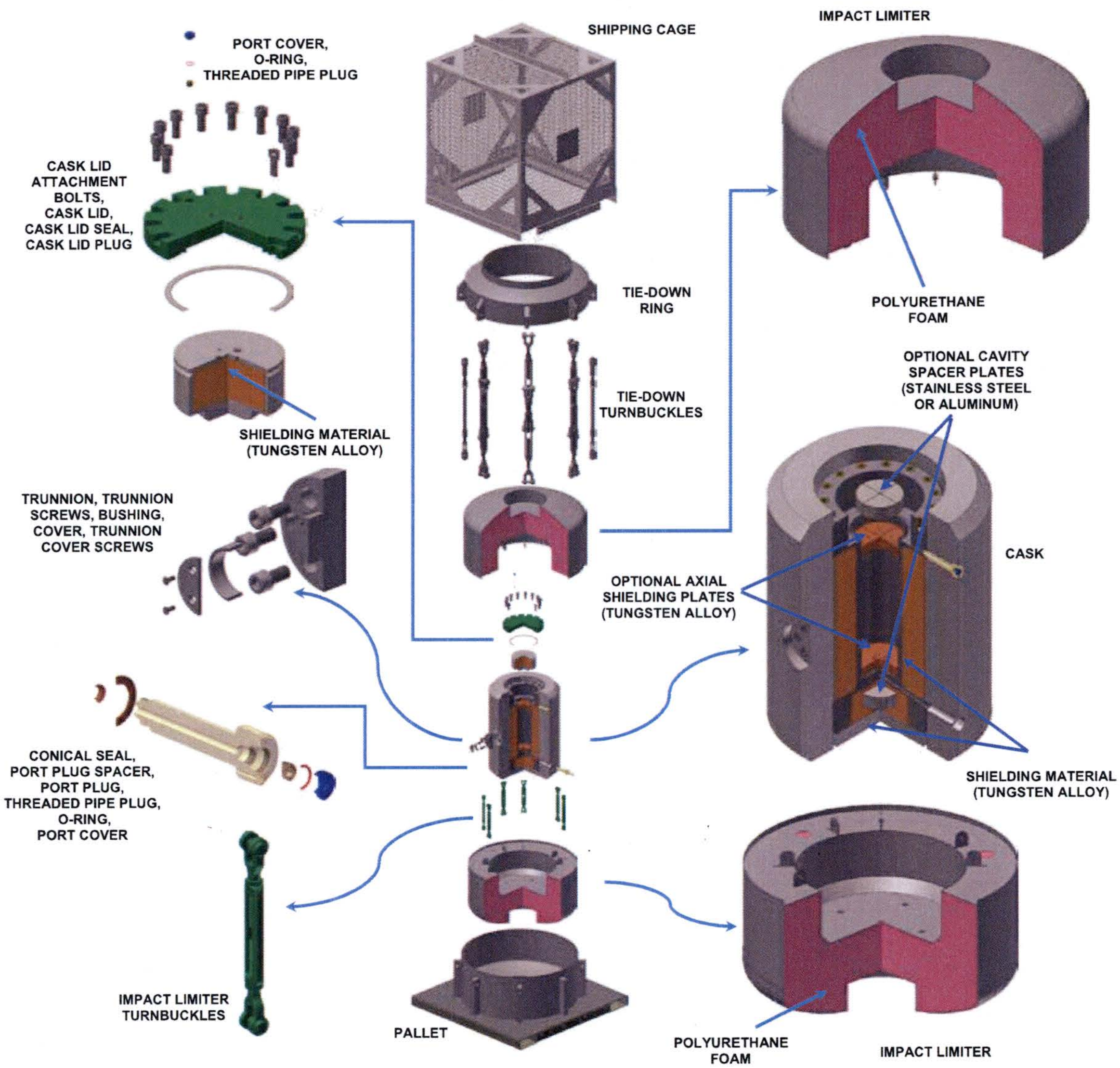

Figure 7-3. Isometric View – Models AOS-100A and AOS-100B

Note: *The Model AOS-100B is identical to the Model AOS-100A, with the exceptions that the Model AOS-100B uses carbon steel as its shielding material, and the optional axial shielding plates and cavity spacer plates are not permitted.*

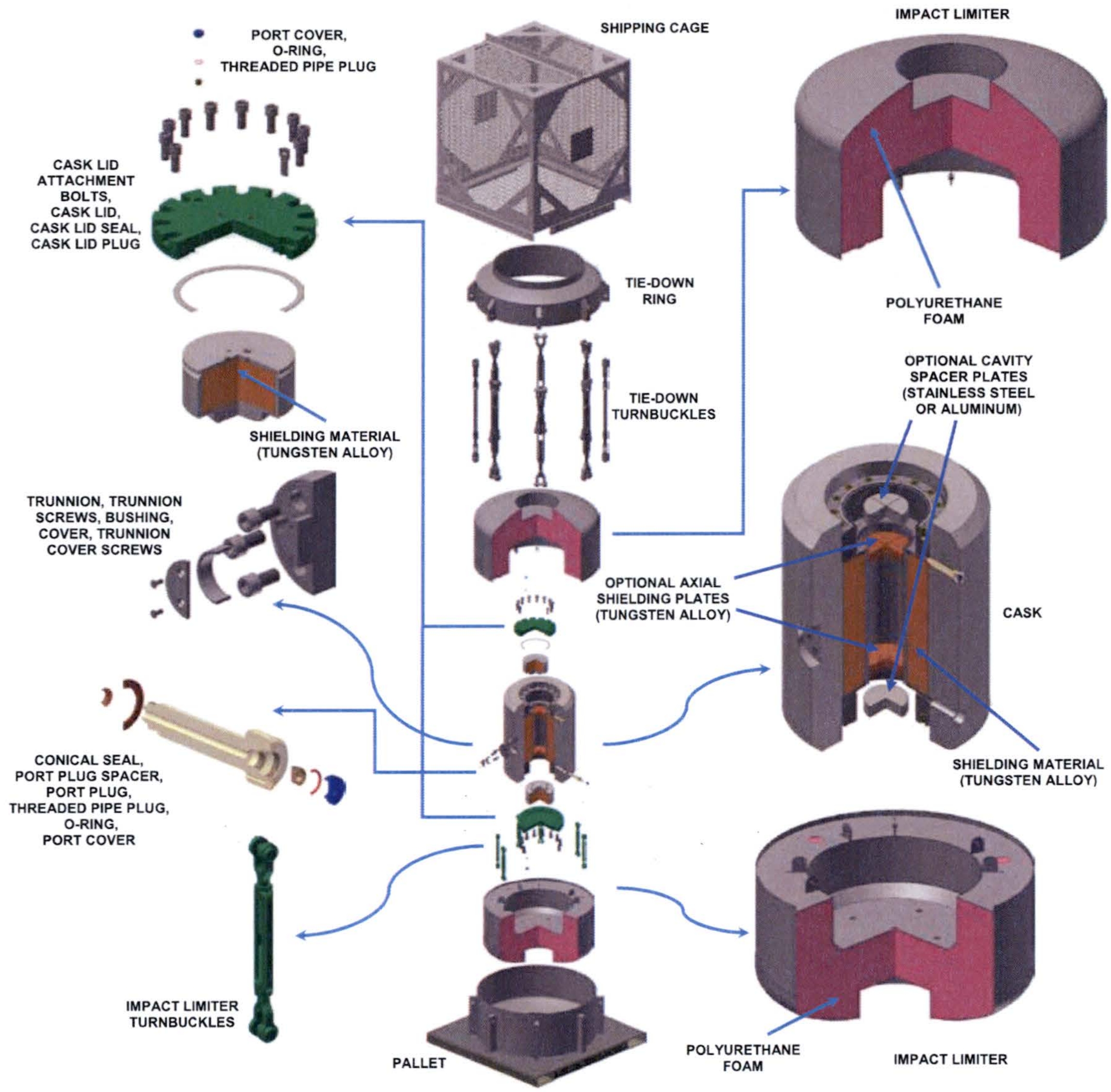

Figure 7-3a. Isometric View – Model AOS-100A-S

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7.1 PACKAGE LOADING

Note: *The operational steps provided in this section apply to all AOS Radioactive Material Transport Packaging System models (Models AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S). Any step specific to a given Model is identified within the step.*

Part of the transport package loading preparation is to perform a Pre-Shipment Engineering Evaluation following *IAEA TS-R-1, Paragraph 502*, *10 CFR 71.87*, and *49 CFR 173.475* (References [7.1], [7.2], and [7.3], respectively). The evaluation is used to ensure that the packaging, with its proposed contents, satisfies the applicable requirements of the transport package's license or certificate. This evaluation includes, but is not limited to, the review of the following:

- Proposed contents' isotopic composition, quantities, and decay heat;
- Proposed contents' form, weight, and geometry. If the content is defined as *Special form*, verify its certification from the competent authorities;
- Identify shoring device to be used. All shoring materials used within the cask cavity must have a melting point greater than (i) 600°F for Co-60 in metallic form and Cs-137 in the form of cesium chloride and (ii) 900°F for all other contents;
- Shielding requirements (use of additional shielding devices may be required for shipment);
- Structural requirements;
- Thermal requirements;
- Pressure requirements;
- Shipping hardware (such as liners, racks, dividers, baskets, and shoring devices);
- Maintenance records.
- Personnel qualification.

In addition, operations at the loading facility must safely support a range of activities, from receiving and inspecting the package, to preparing the loaded transport package for shipment. Each loading facility must provide fully trained personnel and detailed operating procedures to cover these activities.

7.1.1 Preparation for Loading

7.1.1.1 Receiving and Inspecting the Empty Transport Package

To receive and inspect the empty transport package:

a. Position the transport vehicle in the Receiving Inspection area.

b. Visually inspect the transport package for damage and proper labeling and marking. Refer to the shipping paper for shipment category and compare the marking and labels on the package to the requirement of Reference [7.3].

c. Verify that the radiation and contamination levels are in compliance with regulatory requirements – *IAEA TS-R-1, Paragraphs 508* and *530* through *532*, *10 CFR 71.47* and *71.87(i)*, *49 CFR 173.441* and *173.443*, and *10 CFR 20.1906* (References [7.1], [7.2], [7.3], and [7.4], respectively).

d. Record any finding(s), and notify the Job Supervisor for disposition of the finding(s). Findings must be evaluated against *10 CFR 71.95* [7.2], to determine whether they require regulatory notification, so proper action can be taken. The Job Supervisor is the person responsible for direct oversight of the personnel that are performing the work.

7.1.1.2 Removing the Transport Package from the Transport Vehicle

To remove the transport package from the transport vehicle:

a. Position the transport vehicle, in the job staging area, for transport package removal. This operation can be aided by the use of a overhead crane or forklift truck.
b. Position the spreader bar or forks, then connect the appropriate slings and shackles to remove the shipping cage.
c. Remove the shipping cage and tie-down hardware.
d. Depending upon site-specific constraints, do one of the following:
   - Remove the upper impact limiter from the cask, then place the impact limiter into temporary storage.
   - Install trunnions. Prior to the installation, apply an anti-vibration compound on the trunnion bolt threads.
   - Lift and remove the entire package from the transport vehicle, then set down the package in an appropriate location. Next, remove the impact limiters from the cask, and place them into temporary storage.
e. Remove the cask, using the appropriate rigging equipment.
f. Transfer the cask to the loading area.

7.1.2 Loading of Contents

7.1.2.1 Preparing for Loading

To prepare the transport package for loading:

a. Verify that the content to be loaded is authorized by the current transport package's Certificate of Compliance. (Refer to the Pre-Shipment Engineering Evaluation in Section 7.1.)
b. Perform a visual inspection. Note any damage or unusual conditions. If part functionality is impaired, repair or replace the part, as required, and document the repair or replacement, then re-inspect the part. Notification and approval of AOS is required. Replacement or repair of any component requires that all original examinations and tests initially prescribed be performed.
c. Depending upon the particular transport package model, remove the cask trunnions and install a lifting device specific to the facility. If using a forklift to transport the cask, protect the cask surface and secure the cask to the forks with straps. If lifting by crane, with or without a spreader bar, the lifting slings must not make an angle greater than 30°, measured from the vertical.
d. With proper radiological protection and monitoring, remove the cask lid and cask lid plug for visual inspection of the cavity.
e. Record any finding(s), and notify the Job Supervisor for disposition of the finding(s). Findings must be evaluated against *10 CFR 71.95* **[7.2]**, to determine whether they require regulatory notification, so that proper action can be taken.
f. Visually inspect the cask and cask lid sealing surfaces for damage or foreign material. Repair or replace damage noted, as required, then re-inspect.
g. Remove the cask drain port, test port, and cask vent port covers, and pipe plugs.
h. **Optional** – Install the lid guide pins, 90° apart. Use of the lid guide pins is mainly needed for proper alignment of the cask lid with the cask lid attachment bolt holes. The lid guide pins also protect the cask lid elastomeric or metallic seal.

7.1.2.2 Loading Irradiated Hardware or Other Contents

To load contents:

a. Place the radioactive contents to be shipped into a shoring device (such as a rack, basket, or other such device).

   The liner, axial shielding plates, and/or cavity spacer plates listed in Table 7-1 are used during the shipment of radioisotope capsules, either in *Normal* or *Special form*, when identified in the Pre-Shipment Engineering Evaluation (refer to Section 7.1), as required for shipment to meet regulatory requirements.

b. Shore the load within the cavity, if needed.

c. Place the cask lid plug into the cask.

Table 7-1. Additional Required Shielding – Models AOS-025A, AOS-050A, AOS-100A, and AOS-100A-S

Model	Component	Certification Drawing[a]		Comments
AOS-025A	Liner	183C8485		Shielding liner is madatory for all contents (Refer to Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models."
AOS-050A	Axial Shielding Plates[b]	183C8519		Use when additional shielding is required. (Refer to Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models.")
AOS-100A AOS-100A-S	Axial Shielding Plates	183C8491		Use when additional shielding is required. (Refer to Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models.")
	Cavity Spacer Plates	183C8518		

a. *Refer to Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models," for drawing revision levels.*

b. *If the Model AOS-050A axial shielding plates include threaded screw holes, each hole must be filled with a setscrew during shipment.*

7.1.2.3 Installing the Cask Lid

Note: *Visually inspect the cask and lid sealing surfaces, as well as the cask lid seal to be used, for damage that can prevent proper sealing of the sealing joint. Refer to Subsection 8.2.2, "Leakage Tests [8.4]," for detailed inspection of these items. If the cask lid seal (elastomeric or metallic) is replaced, a Maintenance Test must be performed, in accordance with ANSI N14.5 (Reference* **[7.8]**).

To install the cask lid, after verifying that the cask lid seal is properly installed, use proper rigging to slowly lower the cask lid onto the cask. Carefully monitor this operation to ensure that the cask lid is properly aligned. During the placement of the cask lid, two lid guide pins may be installed in the cask lid threaded holes perpendicular to each other to maintain alignment of the cask lid attachment bolt holes with the cask lid threaded holes.

7.1.3.2 Removing the Cask from the Loading Area

To remove the cask from the loading area, in preparation for transport:

a. Carefully measure the cask radiation levels, while removing the cask from the storage basin or cell area.

b. Decontaminate the cask to a level consistent with *IAEA TS-R-1, Paragraph 508, 10 CFR 71.87(i)*, and *49 CFR 173.443* (References [7.1], [7.2], and [7.3], respectively).

7.1.3.3 Pre-Shipment Leak Testing

To verify that the containment system of the transport package is properly assembled for shipment, perform one of the following Pre-Shipment Leak tests – Test A1, A2 or B – depending on the cask lid seal type.

Note: *When the Model AOS-100A-S is used, both cask lid seals must be leak tested.*

Test A1 – Gas Pressure Rise: When Re-Using Elastomeric Cask Lid Seals (Tests: Cask Lid(s), Vent and Drain Ports)

To leak test the containment system:

a. Perform the test by evacuating the space between the cask lid seal's elastomeric O-Ring seals, –or– the cavities outside the cask vent and drain ports, and then measuring the pressure rise.

Note: *The gas pressure rise leak test is performed using a test manifold, isolation valve, vacuum gauge, and vacuum pump. The internal volume of the test apparatus upstream of the isolation valve must be known and considered to achieve the required test sensitivity for the test hold time. Use only the test apparatus described in the test procedure.*

Note: *Leak Test criteria for leak rates must meet the requirement of Reference* [7.8].

b. Connect the test manifold to the test port. Evacuate the test volume to the required level. and then close the isolation valve.

c. Disconnect the vacuum pump and then wait for the prescribed hold time. After the hold time, the acceptance criterion is a pressure rise corresponding to 1×10^{-3}ref-cm^3/sec.

Test A2 – Gas Pressure Drop: When Re-Using Elastomeric Cask Lid Seals (Tests: Cask Lid(s), Vent and Drain Ports)

To leak test the containment system:

a. Perform the test by pressurizing the space between the cask lid seal's elastomeric O-Ring seals, –or– the cavities outside the cask vent and drain ports, and then measuring the pressure drop.

Note: *The gas pressure drop leak test is performed using a test manifold, isolation valve, pressure gauge, and pump. The internal volume of the test apparatus downstream of the isolation valve must be known and considered to achieve the required test sensitivity for the test hold time. Use only the test apparatus described in the test procedure.*

Note: *Leak Test criteria for leak rates must meet the requirement of Reference* [7.8].

b. Connect the test manifold to the test port. Evacuate the test volume to the required level. and then close the isolation valve.

c. Disconnect the pump and then wait for the prescribed hold time. After the hold time, the acceptance criterion is a pressure drop corresponding to 1×10^{-3}ref-cm^3/sec.

Test B – Tracer Gas When Using Metallic Cask Lid Seal (Tests: Lid (Cask Lid Seal), Vent and Drain Ports)

To leak test the containment system:

a. Perform a leak test of the cask lid seal, drain threaded pipe plugs, and vent threaded pipe plugs, with a thermal conductivity sensing instrument or mass spectrometer device with a sensitivity of at least 1.0×10^{-8} ref-cm^3/sec.

b. Set up the test instrument in accordance with written procedures and the instrument manufacturer's guidance.

Note: *Leak Test criteria for leak rates must meet the requirement of Reference* [7.8].

c. Evacuate the cask cavity and then backfill the cask cavity with helium to a pressure of at least one (1) atmosphere.

d. With the instrument selected in step a calibrated with a calibration standard within the range of 1.0×10^{-8} to 5.0×10^{-7} ref-cm^3/sec, check the following for indications of leakage:
   - Package containment with the test instrument, through the test port
   - Volume between the double "C" cross-sections
   - Around the threaded joint area of the drain and vent threaded pipe plugs

e. If leakage greater than 1×10^{-7}ref-cm^3/sec, corrected for the nature of the tracer gas and temperature condition at the time of the test, is detected, repair or replace the damaged component(s), and then re-test for indications of leakage.

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7.1.3.4 Preparing the Cask for Transport of Radioactive Material

To prepare the cask for transporting radioactive material:

a. Transport the cask to the staging area.

b. Perform a radiological survey of all cask surfaces (refer to Table 7-3), to demonstrate compliance with applicable shipping regulations.

Table 7-3. Maximum Distance from Loaded Cask Surface to Take Surface Dose Measurements – All Models

Model	Axial Dose Point Maximum Distance from Cask Surface	Radial Dose Point Maximum Distance from Cask Surface
	in.	in.
AOS-025	2	1
AOS-050	5	3
AOS-100	10	6

c. Remove any site-specific lifting devices from the cask.

Note: *The transport packages require that the lower impact limiter must first be installed on the pallet, before placing the cask in the impact limiter.*

d. Verify that the lower impact limiter is installed on the pallet:

1. **If the lower impact limiter was left on the pallet** – Place the cask into the impact limiter/ pallet assembly.
2. **If the complete transport package was removed** – Place the lower impact limiter on the pallet, then place the cask into the lower impact limiter.

e. Install and secure the upper impact limiter.

f. Verify that the lettering on the identification nameplate is distinguishable and conforms to the Packaging Certification drawing requirement. Re-stamp the lettering or replace the nameplate, if necessary.

g. Remove old shipping labels and apply new ones, based upon the proposed payload, meeting the requirements of *IAEA TS-R-1, Paragraphs 526* and *541* through *543* and/or *49 CFR 172.403* (References **[7.1]** and/or **[7.7]**, respectively).

h. Apply security seals to two (2) opposite latch pins or turnbuckles, as illustrated in Figure 7-5 and Figure 7-6, respectively.

i. Install the shipping cage. If the shipping cage includes the optional lifting bar, install the lifting bar guards so that the lifting bar cannot be used for lifting of the entire package or for tie down.

j. Complete the radiological survey of the transport package and transport vehicle, consistent with *IAEA TS-R-1, Paragraphs 508* and *530* through *532*, *10 CFR 71.47* and *71.87(i)*, *49 CFR 173.441* and *173.433*, and *10 CFR 20.1906* (References **[7.1]**, **[7.2]**, **[7.3]**, and **[7.4]**, respectively).

k. Apply any additional shipping label or marking that might be required to properly represent the transport package and its content, in accordance with Reference **[7.3]**.

l. Intentionally blank.

m. Apply the security seal, if used, to the shipping cage, as illustrated in Figure 7-7.

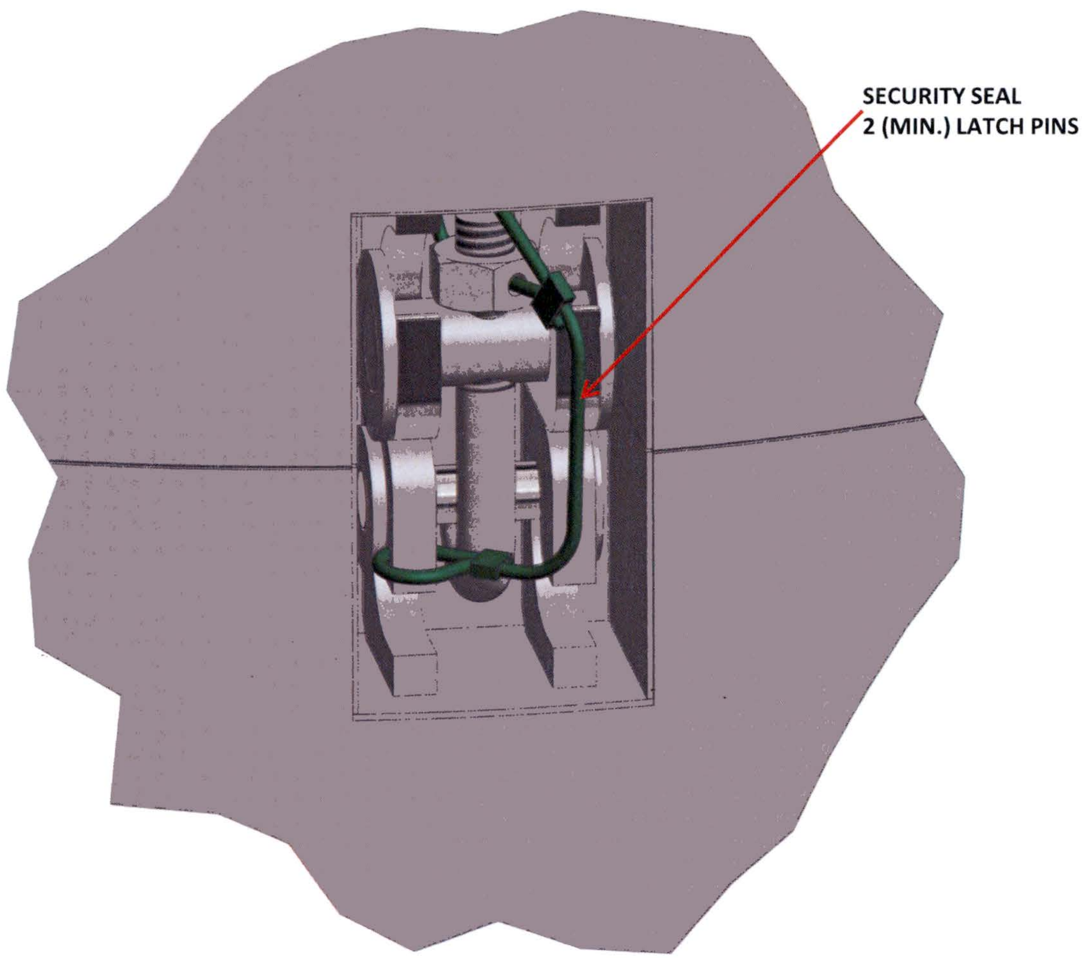

Figure 7-5. Latch Pin Security Seal

7.2 PACKAGE UNLOADING

Note: *The operational steps provided in this section apply to all AOS Radioactive Material Transport Packaging System models (Models AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S). Any step specific to a given Model is identified within the step.*

Operations at the unloading facility are largely the reverse of the loading operations. Each unloading facility must provide fully trained personnel, and supply detailed operating procedures to cover all activities, as required by *10 CFR 71.89* **[7.2]**.

Before handling the packages, consider the following items:

a. Review all shipping manifests against what is expected.

b. Ensure that personnel involved in operations of the AOS Transport Packaging System are familiar with all documents pertinent to the operation and maintenance of the transport packages, and that they have received HAZMAT training, per *49 CFR 172.704* **[7.7]**.

c. Review Table 2-7, "AOS Transport Packaging System Maximum Authorized Package Weight and Cg Locations – All Models" (which lists the packages and their components weights), for the purpose of selecting the proper handling devices.

d. Review Table 3-3, "Maximum Temperature Summary, Normal Conditions of Transport – All Models," Table 3-4, "Maximum Temperature Summary, Hypothetical Accident Conditions of Transport (Condition 3) – All Models," Table 4-6, "Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models," and Table 4-7, "Maximum Cask Cavity Pressure Due to Fire Condition – All Models," to be apprised of the packaging surface temperature and cavity pressures. These values represent maximum conditions.

e. Review the Activity Limits listed in Table 1-2, "Activity Limits (All Isotopes Except Ir-192 and Ir-194) – All Models," and Table 1-2a, "Ir-192 and Ir-194 Activity Limits – All Models." These values represent maximum conditions.

f. Review the AOS Transport Packaging System certification drawings listed in Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models," in preparation for Receiving Inspection.

g. All repairs require AOS approval prior to performing the repairs. Any replacement of components requires notification to AOS.

7.2.1 Receipt of Package from Carrier

To receive the transport package from the carrier:

a. Verify the integrity of the transport package's security seals. If seals are broken, indicating package tampering, isolate the transport package and immediately notify the site's Safeguards organization, then wait for their instructions. Otherwise, remove the security seal, by cutting the wires, then properly dispose of them.

Note: *"Safeguards organization" refers to the organization or person at the facility responsible for radioactive material control and accounting.*

b. Repeat steps a through d in Paragraph 7.1.1.1, and steps b through e in Paragraph 7.1.1.2, to remove the package from the carrier.

c. Perform radiological and smear surveys of the cask surfaces, as described in step a in Paragraph 7.2.2.

7.2.2 Removal of Contents

Note: *The removal of content for all AOS Radioactive Material Transport Packaging System models (Models AOS-025A, AOS-050A, AOS-100A, and AOS-100B) is in the vertical orientation, with the exception of the Model AOS-100A-S, which is in the horizontal orientation.*

To prepare to unload contents:

a. Perform radiological and smear surveys of the cask surfaces. Compare the survey results with the pre-shipment data survey. Report any major discrepancies in the readings to the Job Supervisor, for disposition.
b. Break the tamper-indicating device(s), if applied. In the event that the device is broken, indicating tampering, isolate the cask and immediately notify the site's Safeguards organization, then wait for their instructions.
c. Release the torque of the cask lid attachment bolts, then remove all but five (5) of the bolts, with the exception of the Model AOS-100A-S. For the Model AOS-100A-S, all bolts should remain in place, until the cask is ready to be unloaded.

Note: *At least five (5) cask lid attachment bolts must remain connected, while the cask is in transit within the site facility, for all models except the Model AOS-100A-S.*

d. Transfer the cask to the unloading area.
e. Remove the payload from the cask, following the detailed procedure developed for the facility, based upon the guidelines provided in this chapter.
f. If the cask contents are unloaded underwater or in a hot cell facility, perform the work as specified by the user (site) procedure.
g. After the cask contents are removed, confirm that the cask cavity is empty.

7.2.3 Installing the Cask Lid

Note: *The torque sequence is stamped on the top surface of the cask lid, about the bolt location.*

To install the cask lid:

a. Using proper rigging, slowly lower the cask lid, over the lid guide pins (if used) and onto the cask. Carefully monitor this operation, to ensure that the cask lid is properly aligned.
b. After the cask lid is seated, remove the lid guide pins (if used).

Note: *Verify that the cask contents have been removed and that the cask cavity is empty of all material, before placing the lid onto the cask.*

7.2.4 Removing the Cask from the Staging Area

To remove the cask from the staging area:

a. Install and hand-tighten the cask lid attachment bolts.
b. Remove the cask to the storage area, per user (site) procedure.

7.2.5 Securing the Cask Lid

To secure the cask lid, perform steps b and c in Paragraph 7.3.2.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

Note: *The operational steps provided in this section apply to all AOS Radioactive Material Transport Packaging System models (Models AOS-025A, AOS-050A, AOS-100A, AOS-100B, and AOS-100A-S). Any step specific to a given Model is identified within the step.*

This section describes operations that are typically performed after transporting radioactive material.

7.3.1 Inspecting the Cask Cavity

To inspect the cask cavity:

a. Remove the cask lid and cask lid plug from the empty cask and verify that the cask is empty.

b. Gather the necessary information, per site procedure, so that personnel can certify the transport package is "empty."

c. Perform a radiological survey of the cavity, to determine the extent of any contamination, in accordance with user (site) procedures.

d. If the cask is shipped as "empty," decontaminate the cavity to the limits defined in *IAEA TS-R-1, Paragraph 520*, and *49 CFR 173.428* (References **[7.1]** and **[7.3]**, respectively).

e. Visually inspect the cask cavity and ensure that there is no free-standing water. If free-standing water is present, dry the cask cavity. (The drying instructions are provided in Paragraph 7.1.3.1.)

7.3.2 Installing and Securing the Cask Lid

Note: *Re-use of the lid seal is allowed for empty packaging.*

To install and secure the cask lid:

a. Using proper rigging, slowly lower the cask lid plug and lid onto the cask, over the lid guide pins (if used). Carefully monitor this operation, to ensure that the cask lid is properly aligned.

Note: *The torque sequence is stamped on the top surface of the cask lid, about the bolt location.*

b. Torque the cask lid attachment bolts (refer to Table 7-2) in a crisscross pattern, with a final pass all the way around, to ensure even seal compression.

c. Inspect the cask, to ensure that the cask drain port plugs, cask vent port plugs, and covers are properly installed.

7.3.3 Leak Testing to Verify the Assembly

Not applicable. Leak testing is not performed on empty packaging.

7.3.4 Preparing the Empty Cask for Transport

Decontaminate the external surfaces of the empty cask, to a level consistent with *IAEA TS-R-1, Paragraph 520*, and *49 CFR 173.428* (References **[7.1]** and **[7.3]**, respectively).

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9 QUALITY ASSURANCE PROGRAM

This chapter describes the quality assurance program to be used for the Alpha Omega Services, Inc. (AOS) Transport Packaging System.

9.1 U.S. QUALITY ASSURANCE PROGRAM REQUIREMENTS

AOS maintains a written Quality Assurance (QA) Program in accordance with the requirements of *10 CFR 71, Subpart H* **[9.1]**; and has received, from the U.S. Nuclear Regulatory Commission (USNRC; NRC), QA Program Approval for Radioactive Material Packages No. 0086, Revision 9, dated January 21, 2011. (Refer to Appendix 9.3.1.) This approval satisfies the requirements of *10 CFR 71.17(b)* and *71.101(f)* (Reference **[9.1]**) for a QA Program approved by the NRC, and remains in effect until its expiration on February 28, 2021.

9.2 IAEA QUALITY ASSURANCE PROGRAM REQUIREMENTS

The AOS QA program also satisfies the requirements of *IAEA TS-R-1, Paragraph 306* (Reference **[9.2]**).

9.3 APPENDIX

9.3.1 U.S. Nuclear Regulatory Commission Quality Assurance Program Approval for Radioactive Material Packages No. 0086, Revision 9, Dated January 21, 2011

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

January 21, 2011

Mr. Troy Hedger
President
Alpha-Omega Services, Inc.
9156 Rose Street
P.O. Box 789
Bellflower, CA 90706

SUBJECT: QUALITY ASSURANCE PROGRAM LIMITED CONDITION APPROVAL FOR RADIOACTIVE MATERIAL PACKAGES NO. 0086, REVISION 9

Dear Mr. Hedger:

Enclosed is the Quality Assurance (QA) Program Approval for Radioactive Material Packages No. 0086, Revision No. 9, in response to your letter dated December 6, 2010, ML1034202940. This Approval satisfies the requirements of 10 CFR 71.17(b) and 71.101(f) for a QA Program approved by the U.S. Nuclear Regulatory Commission (NRC).

This Approval will remain in effect until the expiration date, indicated in Block No. 3. Termination of your materials license does not cause this Approval to be automatically terminated. If you wish to renew, amend, or terminate this Approval, please request it in writing.

This letter also serves as a reminder that if you are using or planning to use an NRC-approved packaging, you must be registered for use of that packaging with NRC. Registration for use of NRC-approved packagings should be made pursuant to 10 CFR 71.17(c)(3).

If you have any questions, please contact me at 301-492-3299 or Frank Gee at 301-492-3329.

Sincerely,

David W. Pstrak, Chief
Rules, Inspections, and Operations Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Docket No.: 71-0086

Enclosure: QA Program Approval No. 0086, Rev. 9

NRC FORM 311 (10-2006) 10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

QUALITY ASSURANCE PROGRAM APPROVAL
FOR RADIOACTIVE MATERIAL PACKAGES

1. APPROVAL NUMBER: 0086
REVISION NUMBER: 9

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and Title 10, Code of Federal Regulations, Chapter 1, Part 71, and in reliance on statements and representations heretofore made in Item 5 by the organization named in Item 2, the Quality Assurance Program identified in Item 5 is hereby approved. This approval is issued to satisfy the requirements of Section 71.101 of 10 CFR Part 71. This approval is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

2. NAME: Alpha-Omega Services, Inc.
STREET ADDRESS: 9156 Rose Street P.O. Box 789
CITY: Bellflower
STATE: CA
ZIP CODE: 90706

3. EXPIRATION DATE: February 28, 2021

4. DOCKET NUMBER: 71-0086

5. QUALITY ASSURANCE PROGRAM APPLICATION DATE(S)
June 30, 2004; July 6, 2004; January 8, 2008; and December 6, 2010

6. CONDITIONS

1. Activities conducted regarding transportation packagings for radioactive materials in special form are to be executed under applicable criteria of 10 CFR Part 71, Subpart H. Authorized activities include: design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use of transportation packagings.

2. Records shall be maintained in accordance with the provisions of 10 CFR Part 71. Specifically:

   a. Records of each shipment of licensed material shall be maintained for 3 years after that shipment [10 CFR 71.91(a)].

   b. Records providing evidence of packaging quality shall be maintained for 3 years after the life of the packaging [10 CFR 71.91(d)].

   c. Records describing activities affecting packaging quality shall be maintained for 3 years after this Quality Assurance Program Approval is terminated [10 CFR 71.135].

3. Planned and periodic audits of all aspects of the Quality Assurance Program shall be conducted in accordance with written procedures or checklists, by appropriately trained personnel not having direct responsibility in the areas being audited, in accordance with 10 CFR 71.137.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

SIGNATURE: [signature]
DATE: 1/21/11

DAVID W. PSTRAK, CHIEF
RULES, INSPECTIONS, AND OPERATIONS BRANCH
DIVISION OF SPENT FUEL STORAGE AND TRANSPORTATION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

NRC FORM 311 (10-2006) PRINTED ON RECYCLED PAPER

9.4 REFERENCES

[9.1] U.S. Nuclear Regulatory Commission (NRC), *Title 10, Code of Federal Regulations, Part 71 (10 CFR 71),* "Packaging and Transportation of Radioactive Material."

[9.2] *International Atomic Energy Agency (IAEA) Safety Standards Series No. TS-R-1* (*IAEA TS-R-1*), "Regulations for the Safe Transport of Radioactive Material," 2005 Ed.

In memory of Sean O'Flaherty Fahey, PhD.
CSA Engineering, Inc.

December 4, 1973 – January 22, 2006

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AOS
Alpha-Omega Services, Inc.

Alpha-Omega Services, Inc.
Supplementary Affidavit

March 17, 2016

I, Troy Hedger, being duly sworn, depose and state as follows:

1. I am the CEO of Alpha-Omega Services, Inc. and have been delegated the function of reviewing the information described in paragraph 2, which is sought to be withheld, and have been authorized to apply for its withholding.
2. The information sought to be withheld consists of:
   a. Alpha-Omega Services, Inc.'s drawing numbers: 105E9722, 166D8143, 166D8137, 166D8138, 105E9712, 105E9713 and 105E9719;
3. In designating material as proprietary, Alpha-Omega Services, Inc. utilizes the definition of proprietary information and trade secrets set forth in the American Law Institute's Restatement of Torts, Section 757. This definition provides:

   "A trade secret may consist of any formula, pattern, device or compilation of information which is used in one's business and which gives him an opportunity to obtain an advantage over competitors who do not know or use it...A substantial element of secrecy must exist, so that, except by the use of improper means, there would be difficulty in acquiring information...Some factors to be considered in determining whether given information is one's trade secret are: (1) the extent to which the information is known outside of his business; (2) the extent to which it is known by his employees and others involved in this business; (3) the extent of measures taken by him to guard the secrecy of the Information; (4) the value of the information to him and his competitors; (5) the amount of effort or money expended by him in developing the information; (6) the ease or difficulty with which the information could be properly acquired or duplicated by others."

4. Some examples of categories of information which fit into the definition of proprietary information are:
   a. Information that discloses an apparatus where prevention of its use by Alpha-Omega Services' competitors without license from Alpha-Omega Services constitutes a competitive economic advantage over other companies;
   b. Information which, if used by a competitor, would reduce his expenditure on resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality or licensing of a similar product;
   c. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection;

SEE ATTACHMENT
☐ ACKNOWLEDGMENT
☒ JURAT
DATED 3/17/16 TL

5. Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within the company is limited on a "need to know" basis, and such documents at all times are clearly identified as proprietary.
6. The procedure for approval of external release of such a document is reviewed by higher level management, Project Manager, or other equivalent authority for technical content, competitive effect and determination of the accuracy of the proprietary designation in accordance with the standards enumerated above. Disclosures outside of Alpha-Omega Services, Inc. are generally limited to regulatory bodies, customers and potential customers and their agents, suppliers and licensees only in accordance with appropriate regulatory provisions or proprietary agreements.
7. The documentation mentioned in paragraph 2 above has been evaluated in accordance with the above criteria and procedures and has been found to contain information which is proprietary and which customarily held in confidence by Alpha-Omega Services, Inc.
8. The information mentioned in paragraph 2 provides information in support of the licensing of the AOS Transport Packaging System.
9. The information to the best of my knowledge and belief has consistently been held in confidence by Alpha-Omega Services, Inc., no public disclosure has been made, and it is not available in public sources. All disclosures to third parties have been made pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence.
10. Public disclosure of information sought to be withheld is likely to cause substantial harm to the competitive position of Alpha-Omega Services, Inc. and deprive or reduce the availability of profit-making opportunities because:
    a. It was developed with the expenditure of resources exceeding $4,000,000.
    b. Public availability of this information would deprive Alpha-Omega Services, Inc. of the ability to seek reimbursement and would permit competitors to utilize this information to Alpha-Omega Services, Inc.'s detriment.
    c. Public availability of the information would allow competitors to obtain information at no cost which Alpha-Omega Services, Inc. developed at substantial cost. Use of this information by competitors would give them a competitive advantage over Alpha-Omega Services, Inc. by allowing competitors to design Type B packages at lower cost than Alpha-Omega Services, Inc.

The above initial evidential justification requesting that the information contained in the proprietary document be withheld from public disclosure is further supplemented by the additional following information.

AOS

Alpha-Omega Services, Inc.

Drawings 105E9722, 166D8143, 166D8137, 166D8138, 105E9712, 105E9713, and 105E9719 contain sufficiently detailed information to permit a competitor to copy the AOS Transport Packaging System design. For example, drawing 105E9722, 166D8143, 166D8137, 166D8138, 105E9712, 105E9713 and 105E9719 contain construction details for the package cask and impact limiters.

Alpha-Omega Services, Inc. feels that the information sought to be withheld is truly proprietary in nature. Public disclosure of this information, sought to be withheld, would permit Alpha-Omega Services, Inc.'s competitors in need of similar Type B packaging to construct such packaging without incurring significant development cost. This would place Alpha-Omega Services, Inc. at a competitive disadvantage in making these Type B containers available to the industry.

9156 Rose Street • P.O. Box 789 • Bellflower, California, U.S.A 90706
Customer Service (800) 346-7894 • (562) 804-0604 • Fax: (562) 804-0610
www.alpha-omegaserv.com

AOS
Alpha-Omega Services, Inc.

State of California)ss:
County of San Bernardino)

Troy Hedger, being duly sworn, deposes and says:

That he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information and belief.

Rancho Cucamonga, California, this 17th day of March 2016

Troy Hedger
Alpha-Omega Services, Inc.

Subscribed and sworn before me this 17th day of March ~~20116~~
2016 T

Notary Public, State of California

9156 Rose Street • P.O. Box 789 • Bellflower, California, U.S.A 90706
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JURAT

A notary public or other officer completing this certificate verifies only the identity of the individual who signed the document to which this certificate is attached, and not the truthfulness, accuracy, or validity of that document.

State of California

County of San Bernardino

Subscribed and sworn to (or affirmed) before me on this 17 day of March,

2016 by Troy Hedger,

proved to me on the basis of satisfactory evidence to be the person~~(s)~~ who appeared before me.

T. Lombardo
Signature (Seal)

T. LOMBARDO
COMM. #2022416
Notary Public - California
SAN BERNARDINO COUNTY
My Comm. Exp. Apr. 28, 2017

OPTIONAL INFORMATION

DESCRIPTION OF THE ATTACHED DOCUMENT

Alpha-Omega Services, Inc.
(Title or description of attached document)

Supplementary Affidavit
(Title or description of attached document continued)

Number of Pages 4 Document Date 3/17/16

Additional information

INSTRUCTIONS

The wording of all Jurats completed in California after January 1, 2015 must be in the form as set forth within this Jurat. There are no exceptions. If a Jurat to be completed does not follow this form, the notary must correct the verbiage by using a jurat stamp containing the correct wording or attaching a separate jurat form such as this one with does contain the proper wording. In addition, the notary must require an oath or affirmation from the document signer regarding the truthfulness of the contents of the document. The document must be signed AFTER the oath or affirmation. If the document was previously signed, it must be re-signed in front of the notary public during the jurat process.

- State and county information must be the state and county where the document signer(s) personally appeared before the notary public.
- Date of notarization must be the date the signer(s) personally appeared which must also be the same date the jurat process is completed.
- Print the name(s) of the document signer(s) who personally appear at the time of notarization.
- Signature of the notary public must match the signature on file with the office of the county clerk.
- The notary seal impression must be clear and photographically reproducible. Impression must not cover text or lines. If seal impression smudges, re-seal if a sufficient area permits, otherwise complete a different jurat form.
  - Additional information is not required but could help to ensure this jurat is not misused or attached to a different document.
  - Indicate title or type of attached document, number of pages and date.
- Securely attach this document to the signed document with a staple.