

AOS-FM9054  
October, 2011  
Rev. E 10/11/11  
(Docket No. 71-9316)

# **Radioactive Material Transport Packaging System Safety Analysis Report**

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

**Prepared by  
Alpha-Omega Services, Inc.  
Bellflower, CA**

**with GE Hitachi Nuclear Energy  
Sunol, CA**

NMSSD1

## NOTICE AND DISCLAIMER

Alpha-Omega Services, Inc. and its contractor GE Hitachi Nuclear Energy ("Contractor") solely for the use of the U.S. Nuclear Regulatory Commission (NRC) in licensing the AOS Radioactive Material Transport Packaging System ("AOS Transport Packaging System") prepared this report. Alpha-Omega Services, Inc., and/or its Contractor assume no responsibility for liability nor damage, which may result from any other use of the information disclosed in this report.

The information contained in this report is believed to be an accurate and true representation of the facts known by or provided to Alpha-Omega Services, Inc., and/or its Contractor at the time this report was prepared. Alpha-Omega Services, Inc., and/or its contractor and the individual contributors to this report make no express nor implied warranty with respect to the accuracy, completeness, or usefulness of the information contained in this report, other than for the licensing of the AOS Transport Packaging System or that the use of any information disclosed in this report may not infringe privately owned rights, including patent rights.

The printed copy of this report, as submitted to the NRC, contains PDF files, one or more of which contains hyperlinks to other files (within the report) or to the Internet. These hyperlinks are either inoperable or are not essential to the use of the filing. Any material referenced by hyperlinks to the Internet that was essential for use of this filing has been submitted as part of the filing. Any material referenced by a hyperlink to another PDF that was essential for the use of this filing has either been included by reference or submitted as part of this filing.



# CONTENTS

<b>1. General Information</b>	<b>1-1</b>
1.1. INTRODUCTION	1-1
1.2. PACKAGE DESCRIPTION	1-6
1.2.1. Packaging	1-7
1.2.2. Contents	1-10
1.2.3. Special Requirements for Plutonium	1-12
1.2.4. Operational Features	1-12
1.2.5. Fabrication Codes, Standards, and Acceptance Tests	1-12
1.3. APPENDIX	1-17
1.3.1. AOS Transport Packaging System, Certification Drawings	1-17
1.4. REFERENCES	1-36
 <b>2. Structural Evaluation</b>	 <b>2-1</b>
2.1. DESCRIPTION OF STRUCTURAL DESIGN	2-2
2.1.1. Discussion	2-2
2.1.2. Design Criteria	2-8
2.1.3. Weights and Centers of Gravity	2-23
2.1.4. Identification of Codes and Standards for Package Design	2-27
2.2. MATERIALS	2-29
2.2.1. Material Properties and Specifications	2-29
2.2.2. Chemical, Galvanic, and/or Other Reactions	2-36
2.2.3. Effects of Radiation on Materials	2-37
2.3. FABRICATION AND EXAMINATION	2-38
2.3.1. Fabrication	2-38
2.3.2. Examination	2-42
2.4. GENERAL REQUIREMENTS FOR ALL PACKAGES	2-43
2.4.1. Minimum Package Size	2-43
2.4.2. Tamper-Indicating Feature	2-43
2.4.3. Positive Closure	2-43
2.5. LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES	2-44
2.5.1. Lifting Devices	2-44
2.5.2. Tie-Down Devices	2-49
2.5.3. Other Devices	2-49
2.6. NORMAL CONDITIONS OF TRANSPORT	2-71
2.6.1. Heat	2-71
2.6.2. Cold	2-76
2.6.3. Reduced External Pressure	2-77
2.6.4. Increased External Pressure	2-77
2.6.5. Vibration	2-77
2.6.6. Water Spray	2-79
2.6.7. Free Drop	2-79
2.6.8. Corner Drop	2-80
2.6.9. Compression	2-80
2.6.10. Penetration	2-80
2.6.11. Structural Evaluation Results Summary and Minimum Margins of Safety under Normal Conditions of Transport	2-83
2.7. HYPOTHETICAL ACCIDENT CONDITIONS	2-89
2.7.1. Free Drop	2-89
2.7.2. Crush	2-141
2.7.3. Puncture	2-141
2.7.4. Thermal	2-143
2.7.5. Immersion – Fissile Material	2-148

2.7.6. Immersion – All Packages .....	2-148
2.7.7. Deep Water Immersion Test (for Type B Packages Containing More than $10^5 A_2$ ) .....	2-148
2.7.8. Summary of Damages .....	2-149
2.8. ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM .....	2-154
2.9. ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGE FOR AIR TRANSPORT ....	2-154
2.10. <i>SPECIAL FORM</i> .....	<b>2-154</b>
2.11. FUEL RODS .....	2-154
2.12. APPENDIX .....	2-155
2.12.1. Data CDs .....	2-156
2.12.2. Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100 .....	2-157
2.12.3. LIBRA Finite Element Analysis Program and Verification Problems .....	2-690
2.12.4. Description of LIBRA Files and Post-Processors: AOS Safety Analysis Report .....	2-721
2.12.5. Selected Material Properties References .....	2-747
2.12.6. Impact (Free-Drop) Test Report .....	2-799
2.12.7. Dimensional Inspection Report .....	2-875
2.12.8. Analysis of Content-Cask Lid Impact .....	2-885
2.12.9. Comparison of Libra Static and Dynamic Impact Analysis .....	2-889
2.12.10. Effect of Ribs on Stress at Foam-Cask Interface .....	2-904
2.12.11. Analysis of 30-Ft. Drops with Shipping Cages .....	2-908
2.12.12. Analysis of Tie-Down Devices .....	2-917
2.12.13. Certificate of Conformance, General Plastics FR-3700 Series Foam – AOS-165A Prototype .....	2-937
2.13. REFERENCES .....	2-941

### **3. Thermal Evaluation .....3-1**

3.1. DESCRIPTION OF THERMAL DESIGN .....	3-1
3.1.1. Design Features .....	3-1
3.1.2. Contents' Decay Heat .....	3-2
3.1.3. Summary Tables of Temperatures .....	3-3
3.1.4. Summary Tables of Maximum Pressures .....	3-10
3.2. MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS .....	3-11
3.2.1. Material Properties .....	3-11
3.2.2. Component Specifications .....	3-18
3.3. THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT .....	3-19
3.3.1. Heat and Cold .....	3-19
3.3.2. Maximum Normal Operating Pressure .....	3-20
3.3.3. Thermal Finite Element Model .....	3-21
3.3.4. Normal Conditions of Transport Thermal Results .....	3-45
3.4. THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS .....	3-46
3.4.1. Initial Conditions .....	3-47
3.4.2. Fire Test Conditions .....	3-47
3.4.3. Maximum Temperatures and Pressures .....	3-47
3.4.4. Maximum Thermal Stresses .....	3-47
3.4.5. Accident Conditions for Fissile Material Packages for Air Transport .....	3-47
3.4.6. Hypothetical Accident Conditions of Transport Thermal Results .....	3-48
3.5. APPENDIX .....	3-49
3.5.1. Data CDs .....	3-50
3.5.2. Thermal Evaluation Results – Models AOS-025, AOS-050, and AOS-100 .....	3-51
3.5.3. LIBRA Finite Element Program Heat Transfer Module .....	3-265
3.5.4. Analysis Modeling Data .....	3-271
3.5.5. LIBRA File Input Showing Material Property Assignment .....	3-390
3.5.6. Justification for Use of Uniformly Distributed Decay Heat throughout Cask Cavity .....	3-413
3.5.7. Thermal Tests .....	3-427
3.5.8. Heat Test Report – AOS-165A Prototype .....	3-441

3.5.9. Copper Seal Locations with Analytical Model. ....	3-863
3.5.10. Garlock Helicoflex Report, Helicoflex Seal Temperature Limit. ....	3-867
3.6. REFERENCES .....	3-883

## **4. Containment.....4-1**

4.1. DESCRIPTION OF THE CONTAINMENT SYSTEM.....	4-1
4.1.1. Containment Boundary.....	4-1
4.1.2. Containment Penetrations (Ports) .....	4-4
4.1.3. Cask Lid Metallic Seal .....	4-5
4.1.4. Closure .....	4-7
4.1.5. Keensert Device Evaluation .....	4-17
4.2. CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT .....	4-28
4.2.1. Containment of Radioactive Material .....	4-28
4.2.2. Pressurization of Containment Boundary .....	4-28
4.2.3. Containment Criterion.....	4-29
4.3. CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS.....	4-30
4.3.1. Containment of Radioactive Material .....	4-30
4.3.2. Containment Criterion.....	4-30
4.3.3. Fission Gas Products .....	4-30
4.4. LEAKAGE RATE TESTS FOR TYPE B PACKAGES .....	4-30
4.5. APPENDIX .....	4-31
4.5.1. Garlock Helicoflex Cask Seal Drawings .....	4-33
4.5.2. Fortran Program Used to Analyze Cask Lid Attachment Bolts (Reference [4.6]).....	4-39
4.5.3. Cask Lid Attachment Bolt Fortran Program Input/Output Files.....	4-51
4.6. REFERENCES .....	4-212

## **5. Shielding Evaluation.....5-1**

5.1. DESCRIPTION OF SHIELDING DESIGN.....	5-1
5.1.1. Design Features .....	5-1
5.1.2. Summary Table of Maximum Radiation Levels .....	5-4
5.2. SOURCE SPECIFICATION.....	5-5
5.2.1. Gamma Source .....	5-5
5.2.2. Neutron Source .....	5-6
5.3. SHIELDING MODEL .....	5-7
5.3.1. Configuration of Source and Shielding.....	5-7
5.3.2. Material Properties .....	5-9
5.4. SHIELDING EVALUATION .....	5-10
5.4.1. Methods .....	5-10
5.4.2. Input and Output Data .....	5-13
5.4.3. Flux-to-Dose-Rate Conversion.....	5-14
5.4.4. External Radiation Levels.....	5-15
5.5. APPENDIX .....	5-21
5.5.1. AOS Cask Isotopic Heat Load Calculations .....	5-21
5.5.2. Isotope Values for Calculations .....	5-22
5.5.3. MCNP Input and Output Files for Co-60 Radial Dose Calculation – Model AOS-100A .....	5-28
5.6. REFERENCES .....	5-37

<b>6. Criticality Evaluation .....</b>	<b>6-1</b>
--	------------

<b>7. Package Operations .....</b>	<b>7-1</b>
------------------------------------	------------

7.1. PACKAGE LOADING .....	7-5
7.1.1. Preparation for Loading .....	7-5
7.1.2. Loading of Contents .....	7-6
7.1.3. Preparation for Transport .....	7-8
7.2. PACKAGE UNLOADING .....	7-15
7.2.1. Receipt of Package from Carrier .....	7-15
7.2.2. Removal of Contents .....	7-16
7.2.3. Installing the Cask Lid .....	7-16
7.2.4. Removing the Cask from the Staging Area .....	7-16
7.2.5. Securing the Cask Lid .....	7-16
7.3. PREPARATION OF EMPTY PACKAGE FOR TRANSPORT .....	7-17
7.3.1. Inspecting the Cask Cavity .....	7-17
7.3.2. Installing and Securing the Cask Lid .....	7-17
7.3.3. Leak Testing to Verify the Assembly .....	7-17
7.3.4. Preparing the Empty Cask for Transport .....	7-17
7.4. OTHER OPERATIONS .....	7-18
7.4.1. Records and Reporting Requirements .....	7-18
7.5. APPENDIX (NONE) .....	7-19
7.6. REFERENCES .....	7-19

<b>8. Acceptance Tests and Maintenance Program .....</b>	<b>8-1</b>
--	------------

8.1. ACCEPTANCE TESTS .....	8-1
8.1.1. Visual Inspections and Measurements .....	8-3
8.1.2. Weld Examinations .....	8-3
8.1.3. Structural and Pressure Tests .....	8-3
8.1.4. Leakage Tests .....	8-4
8.1.5. Component and Material Tests .....	8-4
8.1.6. Shielding Tests .....	8-12
8.1.7. Thermal Tests .....	8-13
8.1.8. Miscellaneous Tests .....	8-14
8.2. MAINTENANCE PROGRAM .....	8-15
8.2.1. Structural and Pressure Tests .....	8-15
8.2.2. Leakage Tests .....	8-15
8.2.3. Component and Material Tests .....	8-17
8.2.4. Thermal Tests .....	8-17
8.2.5. Miscellaneous Tests .....	8-17
8.3. APPENDIX (NONE) .....	8-18
8.4. REFERENCES .....	8-18

# FIGURES

## 1. General Information

Figure 1-1.	Isometric View – Model AOS-025A . . . . .	1-3
Figure 1-2.	Isometric View – Model AOS-050A . . . . .	1-4
Figure 1-3.	Isometric View – Models AOS-100A . . . . .	1-5

## 2. Structural Evaluation

Figure 2-1.	Assembled Transport Package Cutaway – Model AOS-025A . . . . .	2-3
Figure 2-2.	Assembled Transport Package Cutaway – Model AOS-050A . . . . .	2-4
Figure 2-3.	Assembled Transport Package Cutaway – Models AOS-100A and AOS-100B . . . . .	2-5
Figure 2-4.	Isometric View – Typical Cask . . . . .	2-6
Figure 2-5.	Isometric View – Typical Impact Limiter . . . . .	2-7
Figure 2-6.	Axisymmetric (2D) Model – Models AOS-025, AOS-050, and AOS-100 . . . . .	2-15
Figure 2-7.	3D Model – Models AOS-025, AOS-050, and AOS-100 . . . . .	2-16
Figure 2-8.	3D Rendered Model – Models AOS-025, AOS-050, and AOS-100 . . . . .	2-16
Figure 2-9.	$P_m$ and $P_b$ Stress Monitoring Points – All Models . . . . .	2-17
Figure 2-10.	Center of Gravity – Model AOS-025 . . . . .	2-24
Figure 2-11.	Center of Gravity – Model AOS-050 . . . . .	2-25
Figure 2-12.	Center of Gravity – Model AOS-100 . . . . .	2-26
Figure 2-13.	Trunnion Area Cross-Section and Force Diagram Associated with Lifting Loads . . . . .	2-44
Figure 2-14.	Mesh Diagonal Tension . . . . .	2-50
Figure 2-15.	Side Drop Impact Forces . . . . .	2-55
Figure 2-16.	Cask and Impact Limiter FEA Model – Model AOS-100 . . . . .	2-57
Figure 2-17.	Cask and Impact Limiter Deformed FEA Model – Model AOS-100 . . . . .	2-57
Figure 2-18.	Critical Stress at Skin and J-Bolt Box Connection – Model AOS-025 . . . . .	2-62
Figure 2-19.	Critical Stress at Rib Connector Pin's Bearing – Models AOS-050 and AOS-100 . . . . .	2-63
Figure 2-20.	LIBRA Liner Model – Model AOS-025 . . . . .	2-66
Figure 2-21.	Equivalent Stress Due to Longitudinal Acceleration – Model AOS-025 . . . . .	2-67
Figure 2-22.	Equivalent Stress Due to Transverse Acceleration – Model AOS-025 . . . . .	2-68
Figure 2-23.	Axial Shield Plate Y-Displacements – Model AOS-100 . . . . .	2-70
Figure 2-24.	Axial Shield Plate Equivalent Stress – Model AOS-100 . . . . .	2-70
Figure 2-25.	Typical Corner Cask Cavity Shell Weld Joint Configuration – All Models . . . . .	2-75
Figure 2-26.	Fixed Points for Shock and Vibration Analyses . . . . .	2-78
Figure 2-27.	Head-On, Side, and Slap-Down Free-Drop Orientations . . . . .	2-80
Figure 2-28.	Rod Impact Analysis Load Distribution – Model AOS-100 . . . . .	2-81
Figure 2-29.	Rod Impact Time History Displacement at Impact Node – Model AOS-100 . . . . .	2-82
Figure 2-30.	Head-On, Side, and Slap-Down Free-Drop Orientations . . . . .	2-90
Figure 2-31.	Test Setup (Head-On Orientation Shown) – AOS-165A Prototype . . . . .	2-92
Figure 2-32.	Finite Element Model of Impact Limiter – Model AOS-100 . . . . .	2-94
Figure 2-33.	Head-On Drop Force and Energy – Model AOS-100 . . . . .	2-94
Figure 2-34.	Head-On Drop, Maximum Foam Displacement (Deformed Model) – Model AOS-100 . . . . .	2-95
Figure 2-35.	Head-On Drop, Maximum Equivalent Stress in Foam – Model AOS-100 . . . . .	2-95
Figure 2-36.	Head-On Drop Analysis Load Distribution – All Models . . . . .	2-96
Figure 2-37.	Sectioned Impact Limiter Used in Head-On Drop – AOS-165A Prototype . . . . .	2-99
Figure 2-38.	Impact Limiter after Head-On Drop – AOS-165A Prototype . . . . .	2-100
Figure 2-39.	Rendered LIBRA Deformed Head-On Drop – AOS-165A Prototype . . . . .	2-101
Figure 2-40.	Photograph Frames from High-Speed Video of Head-On Drop – AOS-165A Prototype . . . . .	2-102
Figure 2-41.	Impact Response for Damping, $\gamma = 0.06$ – AOS-165A Prototype . . . . .	2-103
Figure 2-42.	Head-On Drop Force and Energy – AOS-165A Prototype . . . . .	2-104
Figure 2-43.	Side Drop Force and Energy – Model AOS-100 . . . . .	2-105
Figure 2-44.	Side Drop, Maximum Foam Displacement (Deformed Model) – Model AOS-100 . . . . .	2-106
Figure 2-45.	Side Drop, Maximum Equivalent Stress in Foam – Model AOS-100 . . . . .	2-106
Figure 2-46.	Side Drop, Maximum Principal Strain in Foam – Model AOS-100 . . . . .	2-107

Figure 2-47.	Side Drop Analysis Load Distribution – All Models	2-109
Figure 2-48.	Slap Finite Element Model – AOS-165A Prototype	2-112
Figure 2-49.	Maximum Support Displacement versus Offset – AOS-165A Prototype	2-113
Figure 2-50.	Slap-Down Analysis Support Displacements versus Time – AOS-165A Prototype	2-113
Figure 2-51.	Cg/Corner Drop Analysis Load Distribution – All Models	2-115
Figure 2-52.	Head-On Drop Cask Model	2-118
Figure 2-53.	Side+Slap-Down and Cg/Corner Drop Cask Model	2-119
Figure 2-54.	Force-Displacement for Head-On Drop at 75°F – Model AOS-025	2-120
Figure 2-55.	Force-Displacement for Side Drop at 75°F – Model AOS-025	2-121
Figure 2-56.	Force-Displacement for Cg/Corner Drop at 75°F – Model AOS-025	2-122
Figure 2-57.	Force-Displacement for Head-On Drop at 75°F – Model AOS-050	2-123
Figure 2-58.	Force-Displacement for Side Drop at 75°F – Model AOS-050	2-124
Figure 2-59.	Force-Displacement for Cg/Corner Drop at 75°F – Model AOS-050	2-125
Figure 2-60.	Force-Displacement for Head-On Drop at 75°F – Model AOS-100	2-126
Figure 2-61.	Force-Displacement for Head-On Drop at -40°F – Model AOS-100	2-127
Figure 2-62.	Force-Displacement for Side Drop at 75°F – Model AOS-100	2-128
Figure 2-63.	Force-Displacement for Cg/Corner Drop at 75°F – Model AOS-100	2-129
Figure 2-64.	Impact Load Distributions	2-130
Figure 2-65.	Circumferential Impact Load Distribution for Side and Cg/Corner Drops	2-130
Figure 2-66.	Side Impact Slap-Down Analysis	2-134
Figure 2-67.	FEA Model of Puncture Drop	2-142
Figure 2-68.	Generalized Model of Impact I	2-885
Figure 2-69.	Dynamic Analysis FEA Model	2-890
Figure 2-70.	Cask Displacement Time-History	2-891
Figure 2-71.	Ground Impact Forces in Dynamic Model	2-892
Figure 2-72.	Total Ground Impact Force in Dynamic Model	2-893
Figure 2-73.	Deformed Dynamic Model at Maximum Displacement	2-894
Figure 2-74.	Displacement Contours n Deformed Dynamic Model	2-894
Figure 2-75.	Foam Static Analysis FEA Model	2-895
Figure 2-76.	Deformed Foam Static Model at Maximum Displacement	2-895
Figure 2-77.	Energy and Force Plots for Static Analysis	2-896
Figure 2-78.	Energy and Force Plots for Static Analysis with Bi-Linear Stress-Strain	2-897
Figure 2-79.	FEA Model Used in Rib Study	2-904
Figure 2-80.	FEA Model Section Showing Rib	2-905
Figure 2-81.	Z-Cask Section Z-Displacements	2-906
Figure 2-82.	Cask Section Z-Stress	2-907
Figure 2-83.	Configuration of Cask and Pallet Impact	2-908
Figure 2-84.	AGS Model and Typical Input File	2-909
Figure 2-85.	Bilinear Representation of Head-On Force-Displacement – Model AOS-100	2-911
Figure 2-86.	Trilinear Representation of Cg/Corner Force-Displacement – Model AOS-100	2-912
Figure 2-87.	Model AOS-100 Cg/Corner Pallet and Cask Displacements	2-915
Figure 2-88.	Model AOS-100 Cg/Corner Pallet and Ground Impact Forces	2-915
Figure 2-89.	Tie-Down Schematic	2-917
Figure 2-90.	Bearing Traction Along Line $\theta = 0 - 180$	2-918
Figure 2-91.	Schematic of Lateral Bearing Forces	2-920
Figure 2-92.	Tension Cables – Model AOS-100	2-922
Figure 2-93.	Bearing Pressure and Cable Forces	2-924
Figure 2-94.	FEA Model of Tie-Down Ring	2-926
Figure 2-95.	Lateral (Z) Displacement in Conical Shell – Model AOS-100	2-928
Figure 2-96.	Maximum Principal Membrane Stress – Model AOS-100	2-928
Figure 2-97.	Maximum Principal Membrane Stress – Model AOS-050	2-934
Figure 2-98.	Tie-Down Strap Load – Model AOS-025	2-935
Figure 2-99.	Lateral (Z) Displacement in Conical Shell – Model AOS-050	2-936

### 3. Thermal Evaluation

Figure 3-1.	Analytical FEA Model – Normal Conditions of Transport .....	3-22
Figure 3-2.	Cask Assembly External Surface Identification, Normal Conditions of Transport – All Models (Typical; Surfaces 5, 6, 7, and 8 are not used on Model AOS-025) .....	3-32
Figure 3-3.	Cask Assembly External Surface Identification, Fire Condition – All Models (Typical; Surfaces 5, 6, 7, and 8 are not used on Model AOS-025) .....	3-34
Figure 3-4.	Expanded View of Thermal Model Defining Component Interfaces .....	3-44
Figure 3-5.	Thermal Finite Element Model – Fire Conditions .....	3-46
Figure 3-6.	Selected Nodal Locations for Normal Conditions of Transport – Model AOS-025A .....	3-56
Figure 3-7.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A ...	3-59
Figure 3-8.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A ...	3-60
Figure 3-9.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-63
Figure 3-10.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-64
Figure 3-11.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025A .....	3-66
Figure 3-12.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-025A .....	3-68
Figure 3-13.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A ...	3-71
Figure 3-14.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A ...	3-72
Figure 3-15.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A ...	3-75
Figure 3-16.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A ...	3-76
Figure 3-17.	Selected Nodal Locations for Fire Condition – Model AOS-025A .....	3-78
Figure 3-18.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Tungsten Alloy – Model AOS-025A .....	3-79
Figure 3-19.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Model AOS-025A .....	3-80
Figure 3-20.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Model AOS-025A ....	3-81
Figure 3-21.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-025A .....	3-84
Figure 3-22.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-025A .....	3-85
Figure 3-23.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-88
Figure 3-24.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-89
Figure 3-25.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-92
Figure 3-26.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-93
Figure 3-27.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-96
Figure 3-28.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-97
Figure 3-29.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-100
Figure 3-30.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-101
Figure 3-31.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-025A .....	3-104
Figure 3-32.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-025A .....	3-105
Figure 3-33.	Selected Nodal Locations for Normal Conditions of Transport – Model AOS-050A .....	3-111
Figure 3-34.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A ..	3-114

Figure 3-35.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A . .	3-115
Figure 3-36.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-118
Figure 3-37.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-119
Figure 3-38.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-050A . . . . .	3-121
Figure 3-39.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-050A . . . . .	3-123
Figure 3-40.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A . .	3-126
Figure 3-41.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A . .	3-127
Figure 3-42.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A . .	3-130
Figure 3-43.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A . .	3-131
Figure 3-44.	Selected Nodal Locations for Fire Condition – Model AOS-050A . . . . .	3-133
Figure 3-45.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Tungsten Alloy – Model AOS-050A . . . . .	3-134
Figure 3-46.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Model AOS-050A . . . . .	3-135
Figure 3-47.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Model AOS-050A . .	3-136
Figure 3-48.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-050A . . . . .	3-139
Figure 3-49.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-050A . . . . .	3-140
Figure 3-50.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-143
Figure 3-51.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-144
Figure 3-52.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-147
Figure 3-53.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-148
Figure 3-54.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-151
Figure 3-55.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-152
Figure 3-56.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-155
Figure 3-57.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-156
Figure 3-58.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-050A . . . . .	3-159
Figure 3-59.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-050A . . . . .	3-160
Figure 3-60.	Selected Nodal Locations for Normal Conditions of Transport – Model AOS-100 . . . . .	3-165
Figure 3-61.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S . . . . .	3-168
Figure 3-62.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S . . . . .	3-169
Figure 3-63.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S . . . . .	3-172
Figure 3-64.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S . . . . .	3-173
Figure 3-65.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S . . . . .	3-175
Figure 3-66.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Models AOS-100A and AOS-100A-S . . . . .	3-177



Figure 3-67.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S .....	3-180
Figure 3-68.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S .....	3-181
Figure 3-69.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S .....	3-184
Figure 3-70.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S .....	3-185
Figure 3-71.	Selected Nodal Locations for Fire Condition – Model AOS-100 .....	3-187
Figure 3-72.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Tungsten Alloy – Models AOS-100A and AOS-100A-S .....	3-188
Figure 3-73.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Models AOS-100A and AOS-100A-S .....	3-189
Figure 3-74.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Models AOS-100A and AOS-100A-S .....	3-190
Figure 3-75.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Models AOS-100A and AOS-100A-S .....	3-193
Figure 3-76.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Models AOS-100A and AOS-100A-S .....	3-194
Figure 3-77.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S .....	3-197
Figure 3-78.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S .....	3-198
Figure 3-79.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S .....	3-201
Figure 3-80.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S .....	3-202
Figure 3-81.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S .....	3-205
Figure 3-82.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S .....	3-206
Figure 3-83.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S .....	3-209
Figure 3-84.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S .....	3-210
Figure 3-85.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Models AOS-100A and AOS-100A-S .....	3-213
Figure 3-86.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Models AOS-100A and AOS-100A-S .....	3-214
Figure 3-87.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-100B ..	3-219
Figure 3-88.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-100B ..	3-220
Figure 3-89.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B .....	3-223
Figure 3-90.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-100B .....	3-224
Figure 3-91.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-100B .....	3-226
Figure 3-92.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Entire Model – Model AOS-100B .....	3-228
Figure 3-93.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-100B ..	3-231
Figure 3-94.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-100B ..	3-232
Figure 3-95.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-100B ..	3-235
Figure 3-96.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-100B ..	3-236
Figure 3-97.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Cavity Shell, Cask Lid, Cask Lid Plug, Bottom Plate, and Carbon Steel – Model AOS-100B .....	3-238

Figure 3-98.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Seal Area, Cask Vent Port, Cask Drain Port, and Test Port – Model AOS-100B . . . . .	3-239
Figure 3-99.	Fire for 30 Minutes and Post Fire Cool Down for 7.5 Hours, Temperature versus Time, for Cask Outer Shell and Impact Limiter – Model AOS-100B . . .	3-240
Figure 3-100.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Entire Model – Model AOS-100B . . . . .	3-243
Figure 3-101.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Cask Model – Model AOS-100B . . . . .	3-244
Figure 3-102.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B . . . . .	3-247
Figure 3-103.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-100B . . . . .	3-248
Figure 3-104.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B . . . . .	3-251
Figure 3-105.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-100B . . . . .	3-252
Figure 3-106.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B . . . . .	3-255
Figure 3-107.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Cask Model – Model AOS-100B . . . . .	3-256
Figure 3-108.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B . . . . .	3-259
Figure 3-109.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Cask – Model AOS-100B . . . . .	3-260
Figure 3-110.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Model – Model AOS-100B . . . . .	3-263
Figure 3-111.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Entire Cask – Model AOS-100B . . . . .	3-264
Figure 3-112.	SS304 Stainless Steel Thermal Conductivity . . . . .	3-273
Figure 3-113.	SS304 Stainless Steel Specific Heat . . . . .	3-274
Figure 3-114.	Tungsten Alloy Conductivity . . . . .	3-275
Figure 3-115.	Tungsten Alloy Specific Heat . . . . .	3-276
Figure 3-116.	SA-105 Carbon Steel Conductivity . . . . .	3-278
Figure 3-117.	SA-105 Carbon Steel Specific Heat . . . . .	3-279
Figure 3-118.	Air Conductivity . . . . .	3-281
Figure 3-119.	Air Specific Heat . . . . .	3-282
Figure 3-120.	Air Density . . . . .	3-283
Figure 3-121.	Normal Conditions of Transport Model Dimensions – Model AOS-025 . . . . .	3-284
Figure 3-122.	Normal Conditions of Transport Model Dimensions – Model AOS-050 . . . . .	3-285
Figure 3-123.	Normal Conditions of Transport Model Dimensions – Model AOS-100 . . . . .	3-286
Figure 3-124.	Applied 30-ft. Drop Deformations – Model AOS-025 . . . . .	3-287
Figure 3-125.	Applied 30-ft. Drop Deformations – Model AOS-050 . . . . .	3-288
Figure 3-126.	Applied 30-ft. Drop Deformations – Model AOS-100 . . . . .	3-288
Figure 3-127.	Hypothetical Accident Conditions of Transport Model Dimensions – Model AOS-025 . . . . .	3-289
Figure 3-128.	Hypothetical Accident Conditions of Transport Model Dimensions – Model AOS-050 . . . . .	3-290
Figure 3-129.	Hypothetical Accident Conditions of Transport Model Dimensions – Model AOS-100 . . . . .	3-291
Figure 3-130.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Model AOS-025 . . . . .	3-292
Figure 3-131.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Model AOS-050 . . . . .	3-293
Figure 3-132.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Model AOS-100 . . . . .	3-294
Figure 3-133.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Model AOS-025 . . . . .	3-295
Figure 3-134.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Model AOS-050 . . . . .	3-296
Figure 3-135.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Model AOS-100 . . . . .	3-297

Figure 3-136.	Configuration 1, Impact Limiters with 30-Ft. Head-On Drop Deformation – Model AOS-100A FEA Model . . . . .	3-300
Figure 3-137.	Configuration 2, Impact Limiters with No Deformations – Model AOS-100A FEA Model . . . . .	3-301
Figure 3-138.	Configuration 3, Impact Limiters with Full Crush Deformations from Three (3) Directions of Drop Applied Simultaneously – Model AOS-100A FEA Model . . . . .	3-302
Figure 3-139.	Analysis FEA Model, Normal Conditions of Transport – Model AOS-025. . . . .	3-305
Figure 3-140.	Analysis FEA Model, Normal Conditions of Transport – Model AOS-050. . . . .	3-306
Figure 3-141.	Analysis FEA Model, Normal Conditions of Transport – Model AOS-100A . . . . .	3-307
Figure 3-142.	Analysis FEA Model, Hypothetical Accident Conditions of Transport – Model AOS-025 . . . .	3-308
Figure 3-143.	Analysis FEA Model, Hypothetical Accident Conditions of Transport – Model AOS-050 . . . .	3-309
Figure 3-144.	Analysis FEA Model, Hypothetical Accident Conditions of Transport – Model AOS-100A . . .	3-310
Figure 3-145.	Equivalent Conductivity at Enclosed Gaps 0.0118, 0.0124, 0.0176, 0.0147, 0.0403, and 0.0108 in. – Model AOS-025A. . . . .	3-313
Figure 3-146.	Equivalent Conductivity at Enclosed Gaps 0.0140, 0.0150, 0.0250, 0.0190, 0.0710, and 0.0120 in. – Model AOS-050A. . . . .	3-315
Figure 3-147.	Equivalent Conductivity at Enclosed Gaps 0.0170, 0.0200, 0.0290, and 0.0130 in. – Model AOS-100A. . . . .	3-317
Figure 3-148.	Equivalent Conductivity at Enclosed Gaps 0.0400 and 0.1310 in. – Model AOS-100A . . . . .	3-318
Figure 3-149.	Equivalent Conductivity at Enclosed Gaps 0.0170, 0.0200, 0.0290, and 0.0130 in. – Model AOS-100B. . . . .	3-321
Figure 3-150.	Equivalent Conductivity at Enclosed Gaps 0.0400 and 0.1310 in. – Model AOS-100B . . . . .	3-322
Figure 3-151.	Air Kinematic Viscosity . . . . .	3-324
Figure 3-152.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Model AOS-025. . . . .	3-329
Figure 3-153.	Surface Convective Coefficients at 100°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025. . . . .	3-331
Figure 3-154.	Surface Convective Coefficients at -20°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025. . . . .	3-333
Figure 3-155.	Surface Convective Coefficients at -40°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025. . . . .	3-335
Figure 3-156.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Model AOS-050. . . . .	3-337
Figure 3-157.	Surface Convective Coefficients at 100°F Ambient Temperature for Surfaces 1, 2, 3, and 11, Normal Conditions of Transport – Model AOS-050 . . . . .	3-339
Figure 3-158.	Surface Convective Coefficients at 100°F Ambient Temperature for Surfaces 4, 5, and 6, Normal Conditions of Transport – Model AOS-050 . . . . .	3-340
Figure 3-159.	Surface Convective Coefficients at -20°F Ambient Temperature for Surfaces 1, 2, 3, and 11, Normal Conditions of Transport – Model AOS-050 . . . . .	3-342
Figure 3-160.	Surface Convective Coefficients at -20°F Ambient Temperature for Surfaces 4, 5, and 6, Normal Conditions of Transport – Model AOS-050 . . . . .	3-343
Figure 3-161.	Surface Convective Coefficients at -40°F Ambient Temperature for Surfaces 1, 2, 3, and 11, Normal Conditions of Transport – Model AOS-050 . . . . .	3-345
Figure 3-162.	Surface Convective Coefficients at -40°F Ambient Temperature for Surfaces 4, 5, and 6, Normal Conditions of Transport – Model AOS-050 . . . . .	3-346
Figure 3-163.	Cask Assembly External Surface Identification, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-348
Figure 3-164.	Surface Convective Coefficients at 100°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-350
Figure 3-165.	Surface Convective Coefficients at -20°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-352
Figure 3-166.	Surface Convective Coefficients at -40°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-354
Figure 3-167.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Model AOS-025 . . . . .	3-355
Figure 3-168.	Surface Convective Coefficients at 100°F Ambient Temperature, Fire Condition – Model AOS-025 . . . . .	3-357

Figure 3-169.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Model AOS-050 .....	3-359
Figure 3-170.	Surface Convective Coefficients at 100°F Ambient Temperature for Surfaces 3, 4, 5, 6, 8, and 11, Hypothetical Accident Conditions of Transport – Model AOS-050 .....	3-361
Figure 3-171.	Cask Assembly External Surface Identification, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100B. ....	3-363
Figure 3-172.	Surface Convective Coefficients at 100°F Ambient Temperature, Fire Condition – Models AOS-100A and AOS-100B. ....	3-365
Figure 3-173.	Surface Convective Coefficients under Fire Condition at 1,475°F Environment – All Models .....	3-367
Figure 3-174.	Maximum Decay Heat, 100°F Ambient, 24-Hour Transient with 12-Hour Solar Heat and 12-Hour Cool-Down Cycle, Maximum Temperature for Foam Inside Impact Limiter, Node 9952 – Model AOS-025A .....	3-373
Figure 3-175.	Maximum Decay Heat, 100°F Ambient, 24-Hour Transient with 12-Hour Solar Heat and 12-Hour Cool-Down Cycle, Maximum Temperature for Foam Inside Impact Limiter, Node 9413 – Model AOS-050A .....	3-374
Figure 3-176.	Maximum Decay Heat, 100°F Ambient, 24-Hour Transient with 12-Hour Solar Heat and 12-Hour Cool-Down Cycle, Maximum Temperature for Foam Inside Impact Limiter, Node 9079 – Model AOS-100A .....	3-375
Figure 3-177.	Maximum Decay Heat, 100°F Ambient, 24-Hour Transient with 12-Hour Solar Heat and 12-Hour Cool-Down Cycle, Maximum Temperature for Foam Inside Impact Limiter, Node 9079 – Model AOS-100B .....	3-376
Figure 3-178.	Case 1 – Temperature .....	3-421
Figure 3-179.	Case 2 – Temperature .....	3-422
Figure 3-180.	Case 3 – Temperature .....	3-423
Figure 3-181.	Case 1 – Maximum Principal Stress at Cask Lid Corner. ....	3-424
Figure 3-182.	Case 2 – Maximum Principal Stress at Cask Lid Corner. ....	3-425
Figure 3-183.	Case 3 – Maximum Principal Stress at Cask Lid Corner. ....	3-426
Figure 3-184.	Typical Thermal Test Setup .....	3-428
Figure 3-185.	Test Cask Modeling Features .....	3-430
Figure 3-186.	Instrument Cask Inside Pit .....	3-431
Figure 3-187.	Temperature versus Time – Heat Cycle for Thermocouples 3 through 12 .....	3-433
Figure 3-188.	Temperature versus Time – Heat Cycle for Thermocouples 10 through 16 .....	3-433
Figure 3-189.	Temperature versus Time – Cooling Cycle for Thermocouples 3 through 12. ....	3-434
Figure 3-190.	Temperature versus Time – Cooling Cycle for Thermocouples 10 through 16. ....	3-434
Figure 3-191.	Verification Analysis – Axisymmetric (2D) Model of Test Cask. ....	3-435
Figure 3-192.	Verification Analysis – Heat Cycle Boundary Conditions .....	3-436
Figure 3-193.	Verification Analysis – Cooling Cycle Boundary Conditions .....	3-436
Figure 3-194.	Comparison Test Data versus Analytical Results – Center, Cask Bottom .....	3-437
Figure 3-195.	Comparison Test Data versus Analytical Results – Center, Inside Cask Lid Surface. ....	3-437
Figure 3-196.	Comparison Test Data versus Analytical Results – Center, Outside Cask Lid Surface .....	3-438
Figure 3-197.	Comparison Test Data versus Analytical Results – Middle, Cask Cavity Wall .....	3-438
Figure 3-198.	Comparison Test Data versus Analytical Results – Middle, Outside Wall. ....	3-439
Figure 3-199.	Comparison Test Data versus Analytical Results – Cask Drain Port Area .....	3-439
Figure 3-200.	Comparison Test Data versus Analytical Results – Cask Vent Port Area. ....	3-440
Figure 3-201.	Comparison Test Data versus Analytical Results – Test Port Area .....	3-440
Figure 3-202.	Boundary Nodes Excerpt, Copper Seal Locations – Model AOS-100. ....	3-863
Figure 3-203.	Cask Lid Metallic Seal, Test Port, Cask Vent Port, Cask Vent Port Seal, and Cask Vent Port Conical Seal Boundary Node Detail – Model AOS-100 .....	3-864
Figure 3-204.	Cask Drain Port, Cask Drain Port Seal, and Cask Drain Port Conical Seal Boundary Node Detail – Model AOS-100 .....	3-865

## 4. Containment

Figure 4-1.	Containment Boundary . . . . .	4-2
Figure 4-2.	Typical Corner Cask Cavity Shell Weld Joint Configuration – All Models . . . . .	4-3
Figure 4-3.	Typical Port Plug Configuration . . . . .	4-4
Figure 4-4.	Cask Lid Seal – Metallic (Silver, Nickel Chromium, and Stainless Steel), Double “C” Cross-Section Arrangement . . . . .	4-5
Figure 4-5.	Cask Lid Metallic Seal – Attachment by way of Four (4) Screws, and Leak-Testing Hole . . . . .	4-6
Figure 4-6.	Cask Lid, Cask Lid Attachment Bolt, and Cask Temperature Evaluation Nodes . . . . .	4-7

## 5. Shielding Evaluation

Figure 5-1.	Cross-Sectional View of Cask Components . . . . .	5-1
Figure 5-2.	Cask Component Half-Height – All Models . . . . .	5-2
Figure 5-3.	Weight Window Mesh of Axial and Radial Shielding Cases . . . . .	5-11

## 6. Criticality Evaluation

There are no figures in Chapter 6.

## 7. Package Operations

Figure 7-1.	Isometric View – Model AOS-025A . . . . .	7-2
Figure 7-2.	Isometric View – Model AOS-050A . . . . .	7-3
Figure 7-3.	Isometric View – Models AOS-100A . . . . .	7-4
Figure 7-4.	Typical Vacuum Drying System Setup and Equipment . . . . .	7-9
Figure 7-5.	Latch Pin Security Seal . . . . .	7-12
Figure 7-6.	Turnbuckle Security Seal . . . . .	7-13
Figure 7-7.	Shipping Cage Security Seal . . . . .	7-14

## 8. Acceptance Tests and Maintenance Program

Figure 8-1.	Typical Thermal Test Setup . . . . .	8-14
Figure 8-2.	Cask Lid Metallic Seal – Attachment by way of Four (4) Screws, and Leak-Testing Hole . . . . .	8-16

THIS PAGE INTENTIONALLY LEFT BLANK

# TABLES

## 1. General Information

Table 1-1.	AOS Transport Packaging System Dimensions and Maximum Authorized Package Weight – All Models . . . . .	1-6
Table 1-2.	Activity Limits – All Models . . . . .	1-11
Table 1-3.	Content Limitations – All Models . . . . .	1-11
Table 1-4.	AOS Transport Packaging System Analyses Summary – All Models . . . . .	1-13
Table 1-5.	AOS Transport Packaging System Certification Drawing List – All Models . . . . .	1-17

## 2. Structural Evaluation

Table 2-1.	Summary of Load Combinations for Normal and Hypothetical Accident Conditions of Transport . . . . .	2-10
Table 2-2.	Buckling Stress Values – All Models . . . . .	2-14
Table 2-3.	$P_m$ and $P_b$ Stress Monitoring Section Elements – All Models . . . . .	2-18
Table 2-4.	Load Cases . . . . .	2-19
Table 2-5.	Load Case Designation Summary . . . . .	2-20
Table 2-6.	Load Combinations . . . . .	2-21
Table 2-7.	AOS Transport Packaging System Maximum Authorized Package Weight and Cg Locations – All Models . . . . .	2-23
Table 2-8.	Applicable Codes and Standards for Design, Fabrication, and Testing of the AOS Transport Packaging System . . . . .	2-27
Table 2-9.	Stainless Steel Mechanical Properties (Reference [2.5]) . . . . .	2-30
Table 2-10.	Cask Lid Attachment Bolt Mechanical Properties (Reference [2.5]) . . . . .	2-31
Table 2-11.	Tungsten Alloy Material Mechanical Properties . . . . .	2-32
Table 2-12.	Carbon Steel (SA-105) Material Mechanical Properties (Reference [2.5]) . . . . .	2-32
Table 2-13.	Trunnion Screw Mechanical Properties (Reference [2.5]) – All Models . . . . .	2-33
Table 2-14.	LAST-A-FOAM FR-3700 Series Foam Dynamic Strength, psi, Parallel to Direction of Rise – All Models . . . . .	2-34
Table 2-15.	LAST-A-FOAM FR-3700 Series Foam Dynamic Strength, psi, Perpendicular to Direction of Rise – All Models . . . . .	2-35
Table 2-16.	Permanent Dissimilar Metal Joints within Cask Component . . . . .	2-36
Table 2-17.	Temporary Dissimilar Metal Joints within Cask Component . . . . .	2-36
Table 2-18.	Material Selection of Major AOS Transport Packaging System Components (Typical) . . . . .	2-39
Table 2-19.	Examination Program Summary . . . . .	2-42
Table 2-20.	Lifting Load Analysis – All Models . . . . .	2-46
Table 2-21.	Average Bearing Stress – All Models . . . . .	2-47
Table 2-22.	Maximum Shear Stress, $S_v$ – All Models . . . . .	2-48
Table 2-23.	Calculation of Shipping Cage Margins of Safety – All Models . . . . .	2-51
Table 2-24.	Boundary Forces – Model AOS-025 . . . . .	2-58
Table 2-25.	Boundary Forces – Model AOS-050 . . . . .	2-59
Table 2-26.	Boundary Forces – Model AOS-100 . . . . .	2-60
Table 2-27.	Mechanical Connector Impact Load Summary – All Models . . . . .	2-61
Table 2-28.	Mechanical Connector Loads for 10g Inertia Force – All Models . . . . .	2-61
Table 2-29.	Transport Package Thermal Environment Conditions – All Models . . . . .	2-71
Table 2-30.	Temperature Summary of Normal Conditions of Transport – All Models . . . . .	2-73
Table 2-31.	Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models . . . . .	2-73
Table 2-32.	Stresses Resulting from Load Combinations Associated with Heat Environment under Normal Conditions of Transport – All Models . . . . .	2-76
Table 2-33.	Stresses Resulting from Load Combinations Associated with Cold Environment under Normal Conditions of Transport – All Models . . . . .	2-76
Table 2-34.	Free-Drop Distance – All Models . . . . .	2-79
Table 2-35.	Maximum Displacements in Free Drops, Normal Conditions of Transport – All Models . . . . .	2-79

Table 2-36.	Load Cases under Normal Conditions of Transport Structural Evaluation Results – All Models .....	2-84
Table 2-37.	Load Combinations under Normal Conditions of Transport Structural Evaluation Results – All Models .....	2-85
Table 2-38.	Min MS for Normal Conditions of Transport – Model AOS-025A .....	2-87
Table 2-39.	Min MS for Normal Conditions of Transport – Model AOS-050A .....	2-87
Table 2-40.	Min MS for Normal Conditions of Transport – Model AOS-100A and AOS-100A-S .....	2-88
Table 2-41.	Min MS for Normal Conditions of Transport – Model AOS-100B .....	2-88
Table 2-42.	Side-Drop Analysis and Test, Radial Displacement at Impact Limiters 1 and 2 – AOS-165A Prototype .....	2-110
Table 2-43.	Support Displacements – AOS-165A Prototype .....	2-111
Table 2-44.	Slap-Down Drop Analysis and Test, Radial Displacement at Impact Limiters 1 and 2 – AOS-165A Prototype .....	2-114
Table 2-45.	9-m (30-ft.) Drop Analyses Conducted upon Each Cask Model .....	2-117
Table 2-46.	Shipping Cage Weights Used in LIBRA-AGS Dynamic Response Analyses .....	2-133
Table 2-47.	Loads and Accelerations Determined in Drop Analysis Impact – Model AOS-025 .....	2-135
Table 2-48.	Loads and Accelerations Applied in Cask Stress Analyses – Model AOS-025 .....	2-136
Table 2-49.	Loads Determined in Drop Impact Analyses – Model AOS-050 .....	2-137
Table 2-50.	Loads and Accelerations Applied in Cask Stress Analyses – Model AOS-050 .....	2-138
Table 2-51.	Loads Determined in Drop Analysis – Model AOS-100 .....	2-139
Table 2-52.	Loads and Accelerations Applied in Cask Stress Analyses – Model AOS-100 .....	2-140
Table 2-53.	Temperature Summary of Fire Condition – All Models .....	2-144
Table 2-54.	Maximum Cask Cavity Pressure Due to Fire Condition – All Models .....	2-144
Table 2-55.	Load Cases Associated with Thermal Stresses under Hypothetical Accident Conditions of Transport – All Models .....	2-146
Table 2-56.	Load Combinations Associated with Thermal Stresses under Hypothetical Accident Conditions of Transport – All Models .....	2-147
Table 2-57.	Stresses Resulting from Additional Increased External Pressure under Hypothetical Accident Conditions of Transport – All Models .....	2-148
Table 2-58.	Load Cases Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – All Models .....	2-150
Table 2-59.	Load Combinations Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – All Models .....	2-151
Table 2-60.	Min MS for Hypothetical Accident Conditions of Transport – Model AOS-025A .....	2-152
Table 2-61.	Min MS for Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-152
Table 2-62.	Min MS for Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-153
Table 2-63.	Min MS for Hypothetical Accident Conditions of Transport – Model AOS-100B .....	2-153
Table 2-64.	Load Cases Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-025A .....	2-158
Table 2-65.	Load Combinations Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-025A .....	2-159
Table 2-66.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-025A .....	2-160
Table 2-67.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Normal Conditions of Transport – Model AOS-025A .....	2-162
Table 2-68.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-025A .....	2-164
Table 2-69.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-025A .....	2-166
Table 2-70.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-025A .....	2-168
Table 2-71.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-025A .....	2-170
Table 2-72.	Load Case 201, Internal Design Pressure, 207 kPa (30 psia), Normal Conditions of Transport – Model AOS-025A .....	2-172
Table 2-73.	Load Case 202, Minimum External Pressure, 24 kPa (3.5 psia), Normal Conditions of Transport – Model AOS-025A .....	2-174



Table 2-74.	Load Case 203, Maximum Increased External Pressure, 140 kPa (20 psia), Normal Conditions of Transport – Model AOS-025A. ....	2-176
Table 2-75.	Load Case 204, Additional Increased External Pressure, 2 MPa (290 psia), Normal Conditions of Transport – Model AOS-025A. ....	2-178
Table 2-76.	Load Case 211, Fabrication Stress, Normal Conditions of Transport – Model AOS-025A. ....	2-180
Table 2-77.	Load Case 215, Compression Load (5x weight), Normal Conditions of Transport – Model AOS-025A. ....	2-182
Table 2-78.	Load Case 216, Rod Drop onto Cask, Normal Conditions of Transport – Model AOS-025A. ....	2-184
Table 2-79.	Load Case 221, Forward 10g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-025A. ....	2-186
Table 2-80.	Load Case 222, Lateral 5g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-025A. ....	2-188
Table 2-81.	Load Case 223, Vertical 2g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-025A. ....	2-190
Table 2-82.	Load Case 231, 4-ft. Head-On Drop, Normal Conditions of Transport – Model AOS-025A. ....	2-192
Table 2-83.	Load Case 232, 30-ft. Head-On Drop Impact Test, Normal Conditions, Normal Conditions of Transport – Model AOS-025A. ....	2-194
Table 2-84.	Load Combination 101, Hot Environment, Normal Conditions of Transport – Model AOS-025A. ....	2-196
Table 2-85.	Load Combination 102, Cold Environment, Normal Conditions of Transport – Model AOS-025A. ....	2-198
Table 2-86.	Load Combination 103, Increased External Pressure, Normal Conditions of Transport – Model AOS-025A. ....	2-200
Table 2-87.	Load Combination 104, Minimum External Pressure, Normal Conditions of Transport – Model AOS-025A. ....	2-202
Table 2-88.	Load Combination 105, Cold Environment with Maximum Decay Heat, Normal Conditions of Transport – Model AOS-025A. ....	2-204
Table 2-89.	Load Combination 106, Maximum Pressure, Hot Environment, Normal Conditions of Transport – Model AOS-025A. ....	2-206
Table 2-90.	Load Combination 107, Maximum Pressure, Cold Environment, Normal Conditions of Transport – Model AOS-025A. ....	2-208
Table 2-91.	Load Combination 215, Compression Load, Normal Conditions of Transport – Model AOS-025A. ....	2-210
Table 2-92.	Load Combination 216, Rod Drop, Normal Conditions of Transport – Model AOS-025A. ....	2-212
Table 2-93.	Load Combination 217, Rod Drop, Cold Environment, Normal Conditions of Transport – Model AOS-025A. ....	2-214
Table 2-94.	Load Combination 221, Forward Vibration, Normal Conditions of Transport – Model AOS-025A. ....	2-216
Table 2-95.	Load Combination 222, Lateral Vibration, Normal Conditions of Transport – Model AOS-025A. ....	2-218
Table 2-96.	Load Combination 223, Vertical Vibration, Normal Conditions of Transport – Model AOS-025A. ....	2-220
Table 2-97.	Load Combination 224, Forward Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-025A. ....	2-222
Table 2-98.	Load Combination 225, Lateral Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-025A. ....	2-224
Table 2-99.	Load Combination 226, Vertical Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-025A. ....	2-226
Table 2-100.	Load Combination 231, 4-ft. Head-On Drop, Normal Conditions, Normal Conditions of Transport – Model AOS-025A. ....	2-228
Table 2-101.	Load Combination 232, 30-ft. Head-On Drop, Normal Conditions (Impact Test), Normal Conditions of Transport – Model AOS-025A. ....	2-230
Table 2-102.	Load Combination 233, 4-ft. Drop at Cold Temperature, Normal Conditions of Transport – Model AOS-025A. ....	2-232

Table 2-103.	Load Cases Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-234
Table 2-104.	Load Combinations Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-235
Table 2-105.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-236
Table 2-106.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-238
Table 2-107.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-240
Table 2-108.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-242
Table 2-109.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-244
Table 2-110.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-246
Table 2-111.	Load Case 301, 30-ft. Head-On Drop, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-248
Table 2-112.	Load Case 302, 30-ft. Side Drop + Slap-Down, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-250
Table 2-113.	Load Case 303, 30-ft. Cg/Corner Drop, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-252
Table 2-114.	Load Case 304, 30-ft. Head-On Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-254
Table 2-115.	Load Case 305, 30-ft. Side Drop + Slap-Down at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-256
Table 2-116.	Load Case 306, 30-ft. Cg/Corner Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-258
Table 2-117.	Load Case 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-260
Table 2-118.	Load Combination 301, Head-On Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-262
Table 2-119.	Load Combination 302, Side Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-264
Table 2-120.	Load Combination 303, Cg/Corner Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-266
Table 2-121.	Load Combination 304, Head-On Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-268
Table 2-122.	Load Combination 305, Side Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-270
Table 2-123.	Load Combination 306, Cg/Corner Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-272
Table 2-124.	Load Combination 310, Additional Increased External Pressure (290 psi), Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-274
Table 2-125.	Load Combination 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-276
Table 2-126.	Load Combination 312, 4-ft. Drop onto Rod at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-278
Table 2-127.	Load Combination 350, Fire at 30 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-280
Table 2-128.	Load Combination 351, Post Fire at 60 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-282
Table 2-129.	Load Combination 352, Post Fire at 90 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-284
Table 2-130.	Load Combination 353, Post Fire at 120 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-286
Table 2-131.	Load Combination 354, Post Fire at 150 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A . . . . .	2-288

Table 2-132.	Load Combination 355, Post Fire at 180 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-025A .....	2-290
Table 2-133.	Load Cases Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-050A .....	2-292
Table 2-134.	Load Combinations Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-050A .....	2-293
Table 2-135.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-050A. ....	2-294
Table 2-136.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Normal Conditions of Transport – Model AOS-050A. ....	2-296
Table 2-137.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-050A. ....	2-298
Table 2-138.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-050A. ....	2-300
Table 2-139.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-050A. ....	2-302
Table 2-140.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-050A. ....	2-304
Table 2-141.	Load Case 201, Internal Design Pressure, 414 kPa (60 psia), Normal Conditions of Transport – Model AOS-050A. ....	2-306
Table 2-142.	Load Case 202, Minimum External Pressure, 24 kPa (3.5 psia), Normal Conditions of Transport – Model AOS-050A. ....	2-308
Table 2-143.	Load Case 203, Maximum Increased External Pressure, 140 kPa (20 psia), Normal Conditions of Transport – Model AOS-050A. ....	2-310
Table 2-144.	Load Case 204, Additional Increased External Pressure, 2 MPa (290 psia), Normal Conditions of Transport – Model AOS-050A. ....	2-312
Table 2-145.	Load Case 211, Fabrication Stress, Normal Conditions of Transport – Model AOS-050A. ....	2-314
Table 2-146.	Load Case 215, Compression Load (5x weight), Normal Conditions of Transport – Model AOS-050A. ....	2-316
Table 2-147.	Load Case 216, Rod Drop onto Cask, Normal Conditions of Transport – Model AOS-050A. ....	2-318
Table 2-148.	Load Case 221, Forward 10g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-050A. ....	2-320
Table 2-149.	Load Case 222, Lateral 5g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-050A. ....	2-322
Table 2-150.	Load Case 223, Vertical 2g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-050A. ....	2-324
Table 2-151.	Load Case 231, 4-ft. Head-On Drop, Normal Conditions of Transport – Model AOS-050A ..	2-326
Table 2-152.	Load Case 232, 30-ft. Head-On Drop Impact Test, Normal Conditions, Normal Conditions of Transport – Model AOS-050A. ....	2-328
Table 2-153.	Load Combination 101, Hot Environment, Normal Conditions of Transport – Model AOS-050A. ....	2-330
Table 2-154.	Load Combination 102, Cold Environment, Normal Conditions of Transport – Model AOS-050A. ....	2-332
Table 2-155.	Load Combination 103, Increased External Pressure, Normal Conditions of Transport – Model AOS-050A. ....	2-334
Table 2-156.	Load Combination 104, Minimum External Pressure, Normal Conditions of Transport – Model AOS-050A. ....	2-336
Table 2-157.	Load Combination 105, Cold Environment with Maximum Decay Heat, Normal Conditions of Transport – Model AOS-050A. ....	2-338
Table 2-158.	Load Combination 106, Maximum Pressure, Hot Environment, Normal Conditions of Transport – Model AOS-050A. ....	2-340
Table 2-159.	Load Combination 107, Maximum Pressure, Cold Environment, Normal Conditions of Transport – Model AOS-050A. ....	2-342
Table 2-160.	Load Combination 215, Compression Load, Normal Conditions of Transport – Model AOS-050A. ....	2-344
Table 2-161.	Load Combination 216, Rod Drop, Normal Conditions of Transport – Model AOS-050A. ....	2-346

Table 2-162.	Load Combination 217, Rod Drop, Cold Environment, Normal Conditions of Transport – Model AOS-050A. ....	2-348
Table 2-163.	Load Combination 221, Forward Vibration, Normal Conditions of Transport – Model AOS-050A. ....	2-350
Table 2-164.	Load Combination 222, Lateral Vibration, Normal Conditions of Transport – Model AOS-050A. ....	2-352
Table 2-165.	Load Combination 223, Vertical Vibration, Normal Conditions of Transport – Model AOS-050A. ....	2-354
Table 2-166.	Load Combination 224, Forward Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-050A. ....	2-356
Table 2-167.	Load Combination 225, Lateral Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-050A. ....	2-358
Table 2-168.	Load Combination 226, Vertical Vibration at Cold Temperature, Normal Conditions of Transport – Model AOS-050A. ....	2-360
Table 2-169.	Load Combination 231, 4-ft. Head-On Drop, Normal Conditions, Normal Conditions of Transport – Model AOS-050A. ....	2-362
Table 2-170.	Load Combination 232, 30-ft. Head-On Drop, Normal Conditions (Impact Test), Normal Conditions of Transport – Model AOS-050A. ....	2-364
Table 2-171.	Load Combination 233, 4-ft. Drop at Cold Temperature, Normal Conditions of Transport – Model AOS-050A. ....	2-366
Table 2-172.	Load Cases Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-368
Table 2-173.	Load Combinations Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-369
Table 2-174.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-370
Table 2-175.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ...	2-372
Table 2-176.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ...	2-374
Table 2-177.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ...	2-376
Table 2-178.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ...	2-378
Table 2-179.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ...	2-380
Table 2-180.	Load Case 301, 30-ft. Head-On Drop, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-382
Table 2-181.	Load Case 302, 30-ft. Side Drop + Slap-Down, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-384
Table 2-182.	Load Case 303, 30-ft. Cg/Corner Drop, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-386
Table 2-183.	Load Case 304, 30-ft. Head-On Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-388
Table 2-184.	Load Case 305, 30-ft. Side Drop + Slap-Down at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-390
Table 2-185.	Load Case 306, 30-ft. Cg/Corner Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-392
Table 2-186.	Load Case 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-394
Table 2-187.	Load Combination 301, Head-On Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-396
Table 2-188.	Load Combination 302, Side Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-398
Table 2-189.	Load Combination 303, Cg/Corner Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-400
Table 2-190.	Load Combination 304, Head-On Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-050A. ....	2-402

Table 2-191.	Load Combination 305, Side Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-404
Table 2-192.	Load Combination 306, Cg/Corner Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-406
Table 2-193.	Load Combination 310, Additional Increased External Pressure (290 psi), Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-408
Table 2-194.	Load Combination 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-410
Table 2-195.	Load Combination 312, 4-ft. Drop onto Rod at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-412
Table 2-196.	Load Combination 350, Fire at 30 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-414
Table 2-197.	Load Combination 351, Post Fire at 60 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-416
Table 2-198.	Load Combination 352, Post Fire at 90 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-418
Table 2-199.	Load Combination 353, Post Fire at 120 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-420
Table 2-200.	Load Combination 354, Post Fire at 150 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-422
Table 2-201.	Load Combination 355, Post Fire at 180 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-050A .....	2-424
Table 2-202.	Load Cases Associated with Allowable Stresses under Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-426
Table 2-203.	Load Combinations Associated with Allowable Stresses under Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-427
Table 2-204.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-428
Table 2-205.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-430
Table 2-206.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-432
Table 2-207.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-434
Table 2-208.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-436
Table 2-209.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-438
Table 2-210.	Load Case 201, Internal Design Pressure, 1,930 kPa (280 psia), Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-440
Table 2-211.	Load Case 202, Minimum External Pressure, 24 kPa (3.5 psia), Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-442
Table 2-212.	Load Case 203, Maximum Increased External Pressure, 140 kPa (20 psia), Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-444
Table 2-213.	Load Case 204, Additional Increased External Pressure, 2 MPa (290 psia), Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-446
Table 2-214.	Load Case 211, Fabrication Stress, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-448
Table 2-215.	Load Case 215, Compression Load (5x weight), Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-450
Table 2-216.	Load Case 216, Rod Drop onto Cask, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-452
Table 2-217.	Load Case 221, Forward 10g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-454
Table 2-218.	Load Case 222, Lateral 5g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-456
Table 2-219.	Load Case 223, Vertical 2g Vibration Inertia Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-458

Table 2-220.	Load Case 231, 3-ft. Head-On Drop, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-460
Table 2-221.	Load Case 232, 30-ft. Head-On Drop Impact Test, Normal Conditions, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-462
Table 2-222.	Load Combination 101, Hot Environment, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-464
Table 2-223.	Load Combination 102, Cold Environment, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-466
Table 2-224.	Load Combination 103, Increased External Pressure, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-468
Table 2-225.	Load Combination 104, Minimum External Pressure, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-470
Table 2-226.	Load Combination 105, Cold Environment with Maximum Decay Heat, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-472
Table 2-227.	Load Combination 106, Maximum Pressure, Hot Environment, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-474
Table 2-228.	Load Combination 107, Maximum Pressure, Cold Environment, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-476
Table 2-229.	Load Combination 215, Compression Load, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-478
Table 2-230.	Load Combination 216, Rod Drop, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-480
Table 2-231.	Load Combination 217, Rod Drop, Cold Environment, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-482
Table 2-232.	Load Combination 221, Forward Vibration, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-484
Table 2-233.	Load Combination 222, Lateral Vibration, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-486
Table 2-234.	Load Combination 223, Vertical Vibration, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-488
Table 2-235.	Load Combination 224, Forward Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-490
Table 2-236.	Load Combination 225, Lateral Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-492
Table 2-237.	Load Combination 226, Vertical Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-494
Table 2-238.	Load Combination 231, 3-ft. Head-On Drop, Normal Conditions, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-496
Table 2-239.	Load Combination 233, 3-ft. Drop at Cold Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-498
Table 2-240.	Load Cases Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-500
Table 2-241.	Load Combinations Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-501
Table 2-242.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-502
Table 2-243.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-504
Table 2-244.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-506
Table 2-245.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-508
Table 2-246.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-510
Table 2-247.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S .....	2-512

Table 2-248.	Load Case 301, 30-ft. Head-On Drop, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-514
Table 2-249.	Load Case 302, 30-ft. Side Drop + Slap-Down, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-516
Table 2-250.	Load Case 303, 30-ft. Cg/Corner Drop, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-518
Table 2-251.	Load Case 304, 30-ft. Head-On Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-520
Table 2-252.	Load Case 305, 30-ft. Side Drop + Slap-Down at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-522
Table 2-253.	Load Case 306, 30-ft. Cg/Corner Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-524
Table 2-254.	Load Case 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-526
Table 2-255.	Load Combination 301, Head-On Drop Orientation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-528
Table 2-256.	Load Combination 302, Side Drop Orientation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-530
Table 2-257.	Load Combination 303, Cg/Corner Drop Orientation, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-532
Table 2-258.	Load Combination 304, Head-On Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-534
Table 2-259.	Load Combination 305, Side Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-536
Table 2-260.	Load Combination 306, Cg/Corner Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-538
Table 2-261.	Load Combination 310, Additional Increased External Pressure (290 psi), Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-540
Table 2-262.	Load Combination 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-542
Table 2-263.	Load Combination 312, 4-ft. Drop onto Rod at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-544
Table 2-264.	Load Combination 350, Fire at 30 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-546
Table 2-265.	Load Combination 351, Post Fire at 60 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-548
Table 2-266.	Load Combination 352, Post Fire at 90 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-550
Table 2-267.	Load Combination 353, Post Fire at 120 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-552
Table 2-268.	Load Combination 354, Post Fire at 150 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-554
Table 2-269.	Load Combination 355, Post Fire at 180 Minutes, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100A-S. . . . .	2-556
Table 2-270.	Load Cases Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-100B . . . . .	2-558
Table 2-271.	Load Combinations Associated with Allowable Stresses under Normal Conditions of Transport – Model AOS-100B . . . . .	2-559
Table 2-272.	Load Case 101, 100°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-100B. . . . .	2-560
Table 2-273.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Normal Conditions of Transport – Model AOS-100B. . . . .	2-562
Table 2-274.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-100B. . . . .	2-564
Table 2-275.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation, Normal Conditions of Transport – Model AOS-100B. . . . .	2-566
Table 2-276.	Load Case 105, -40°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-100B. . . . .	2-568

Table 2-277.	Load Case 106, -20°F Ambient, Maximum Decay Heat, Normal Conditions of Transport – Model AOS-100B. ....	2-570
Table 2-278.	Load Case 201, Internal Design Pressure, 1,930 kPa (280 psia), Normal Conditions of Transport – Model AOS-100B. ....	2-572
Table 2-279.	Load Case 202, Minimum External Pressure, 24 kPa (3.5 psia), Normal Conditions of Transport – Model AOS-100B. ....	2-574
Table 2-280.	Load Case 203, Maximum Increased External Pressure, 140 kPa (20 psia), Normal Conditions of Transport – Model AOS-100B. ....	2-576
Table 2-281.	Load Case 204, Additional Increased External Pressure, 2 MPa (290 psia), Normal Conditions of Transport – Model AOS-100B. ....	2-578
Table 2-282.	Load Case 211, Fabrication Stress, Normal Conditions of Transport – Model AOS-100B. ....	2-580
Table 2-283.	Load Case 215, Compression Load (5x weight), Normal Conditions of Transport – Model AOS-100B. ....	2-582
Table 2-284.	Load Case 216, Rod Drop onto Cask, Normal Conditions of Transport – Model AOS-100B. ....	2-584
Table 2-285.	Load Case 221, Forward 10g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-100B. ....	2-586
Table 2-286.	Load Case 222, Lateral 5g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-100B. ....	2-588
Table 2-287.	Load Case 223, Vertical 2g Vibration Inertia Load, Normal Conditions of Transport – Model AOS-100B. ....	2-590
Table 2-288.	Load Case 231, 3-ft. Head-On Drop, Normal Conditions of Transport – Model AOS-100B. ....	2-592
Table 2-289.	Load Case 232, 30-ft. Head-On Drop Impact Test, Normal Conditions, Normal Conditions of Transport – Model AOS-100B. ....	2-594
Table 2-290.	Load Combination 101, Hot Environment, Normal Conditions of Transport – Model AOS-100B. ....	2-596
Table 2-291.	Load Combination 102, Cold Environment, Normal Conditions of Transport – Model AOS-100B. ....	2-598
Table 2-292.	Load Combination 103, Increased External Pressure, Normal Conditions of Transport – Model AOS-100B. ....	2-600
Table 2-293.	Load Combination 104, Minimum External Pressure, Normal Conditions of Transport – Model AOS-100B. ....	2-602
Table 2-294.	Load Combination 105, Cold Environment with Maximum Decay Heat, Normal Conditions of Transport – Model AOS-100B. ....	2-604
Table 2-295.	Load Combination 106, Maximum Pressure, Hot Environment, Normal Conditions of Transport – Model AOS-100B. ....	2-606
Table 2-296.	Load Combination 107, Maximum Pressure, Cold Environment, Normal Conditions of Transport – Model AOS-100B. ....	2-608
Table 2-297.	Load Combination 215, Compression Load, Normal Conditions of Transport – Model AOS-100B. ....	2-610
Table 2-298.	Load Combination 216, Rod Drop, Normal Conditions of Transport – Model AOS-100B. ....	2-612
Table 2-299.	Load Combination 217, Rod Drop, Cold Environment, Normal Conditions of Transport – Model AOS-100B. ....	2-614
Table 2-300.	Load Combination 221, Forward Vibration, Normal Conditions of Transport – Model AOS-100B. ....	2-616
Table 2-301.	Load Combination 222, Lateral Vibration, Normal Conditions of Transport – Model AOS-100B. ....	2-618
Table 2-302.	Load Combination 223, Vertical Vibration, Normal Conditions of Transport – Model AOS-100B. ....	2-620
Table 2-303.	Load Combination 224, Forward Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100B. ....	2-622
Table 2-304.	Load Combination 225, Lateral Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100B. ....	2-624
Table 2-305.	Load Combination 226, Vertical Vibration at Cold Temperature, Normal Conditions of Transport – Models AOS-100B. ....	2-626



Table 2-306.	Load Combination 231, 3-ft. Head-On Drop, Normal Conditions, Normal Conditions of Transport – Model AOS-100B . . . . .	2-628
Table 2-307.	Load Combination 233, 3-ft. Drop at Cold Temperature, Normal Conditions of Transport – Models AOS-100B . . . . .	2-630
Table 2-308.	Load Cases Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-632
Table 2-309.	Load Combinations Associated with Allowable Stresses under Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-633
Table 2-310.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-634
Table 2-311.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . .	2-636
Table 2-312.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . .	2-638
Table 2-313.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . .	2-640
Table 2-314.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . .	2-642
Table 2-315.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . .	2-644
Table 2-316.	Load Case 301, 30-ft. Head-On Drop, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-646
Table 2-317.	Load Case 302, 30-ft. Side Drop + Slap-Down, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-648
Table 2-318.	Load Case 303, 30-ft. Cg/Corner Drop, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-650
Table 2-319.	Load Case 304, 30-ft. Head-On Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-652
Table 2-320.	Load Case 305, 30-ft. Side Drop + Slap-Down at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-654
Table 2-321.	Load Case 306, 30-ft. Cg/Corner Drop at -40°F, Low Temperature, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-656
Table 2-322.	Load Case 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-658
Table 2-323.	Load Combination 301, Head-On Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-660
Table 2-324.	Load Combination 302, Side Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-662
Table 2-325.	Load Combination 303, Cg/Corner Drop Orientation, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-664
Table 2-326.	Load Combination 304, Head-On Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-666
Table 2-327.	Load Combination 305, Side Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-668
Table 2-328.	Load Combination 306, Cg/Corner Drop Orientation at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-670
Table 2-329.	Load Combination 310, Additional Increased External Pressure (290 psi), Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-672
Table 2-330.	Load Combination 311, 4-ft. Drop onto Rod, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-674
Table 2-331.	Load Combination 312, 4-ft. Drop onto Rod at -40°F, Cold Environment, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-676
Table 2-332.	Load Combination 350, Fire at 30 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-678
Table 2-333.	Load Combination 351, Post Fire at 60 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-680
Table 2-334.	Load Combination 352, Post Fire at 90 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B . . . . .	2-682

Table 2-335.	Load Combination 353, Post Fire at 120 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B .....	2-684
Table 2-336.	Load Combination 354, Post Fire at 150 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B .....	2-686
Table 2-337.	Load Combination 355, Post Fire at 180 Minutes, Hypothetical Accident Conditions of Transport – Model AOS-100B .....	2-688
Table 2-338.	Generalized Stiffness Properties – All Models .....	2-910
Table 2-339.	Generalized Pallet and Cask Mass Properties – All Models .....	2-910
Table 2-340.	AGS Analysis – Model AOS-025 .....	2-913
Table 2-341.	AGS Analysis – Model AOS-050 .....	2-914
Table 2-342.	AGS Analysis – Model AOS-100 .....	2-914
Table 2-343.	Increased Ground Impact Forces – All Models .....	2-914
Table 2-344.	Model AOS-100 Cable Loads .....	2-922

### 3. Thermal Evaluation

Table 3-1.	Transport Package Thermal Environment Conditions – All Models .....	3-2
Table 3-2.	Contents' Decay Heat – All Models .....	3-2
Table 3-3.	Maximum Temperature Summary, Normal Conditions of Transport – All Models .....	3-3
Table 3-4.	Maximum Temperature Summary, Hypothetical Accident Conditions of Transport (Condition 3) – All Models .....	3-7
Table 3-5.	Type 304 Stainless Steel (SS304) Thermophysical Properties (Reference [3.16]) .....	3-12
Table 3-6.	Tungsten Alloy Thermophysical Properties (Reference [3.3]) – Models AOS-025A, AOS-050A, AOS-100A, and AOS-100A-S .....	3-13
Table 3-7.	Carbon Steel Properties – Model AOS-100B (Reference [3.16]) .....	3-14
Table 3-8.	Air Thermophysical Properties (Reference [3.4]) .....	3-16
Table 3-9.	LAST-A-FOAM FR-3700 Series Foam Thermophysical Properties – All Models (Reference [3.19]) .....	3-17
Table 3-10.	Heat Flux Values – All Models .....	3-24
Table 3-11.	Thermal Properties Used in Analysis as Function of Temperature, with Respect to the Air Gaps – All Models .....	3-29
Table 3-12.	Cask Assembly External Surface Orientation and Size, Normal Conditions of Transport – All Models .....	3-31
Table 3-13.	Cask Assembly External Surface Orientation and Size, Fire Condition – All Models .....	3-33
Table 3-14.	Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Normal Conditions of Transport – All Models .....	3-36
Table 3-15.	Polynomial Coefficients Used in Equivalent Convective Property of Ambient Temperature and External Surface, Steady-State Leading to the Fire and Cool-Down Conditions – All Models .....	3-39
Table 3-16.	Solar Heat Application to Cask Outside Surfaces – All Models .....	3-42
Table 3-17.	Temperature Monitoring Points by Condition – Model AOS-025A .....	3-53
Table 3-18.	Normal Conditions of Transport Thermal Evaluation Results – Model AOS-025A .....	3-55
Table 3-19.	Load Case 101, 100°F Ambient, Maximum Decay Heat – Model AOS-025A .....	3-57
Table 3-20.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-025A .....	3-61
Table 3-21.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025A .....	3-65
Table 3-22.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-025A .....	3-67
Table 3-23.	Load Case 105, -40°F Ambient, Maximum Decay Heat – Model AOS-025A .....	3-69
Table 3-24.	Load Case 106, -20°F Ambient, Maximum Decay Heat – Model AOS-025A .....	3-73
Table 3-25.	Fire Condition Thermal Evaluation Results – Model AOS-025A .....	3-77
Table 3-26.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Model AOS-025A .....	3-82
Table 3-27.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A .....	3-86
Table 3-28.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A .....	3-90

Table 3-29.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A. ....	3-94
Table 3-30.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A. ....	3-98
Table 3-31.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-025A. ....	3-102
Table 3-32.	Temperature Monitoring Points, by Condition – Model AOS-050A. ....	3-108
Table 3-33.	Normal Conditions of Transport Thermal Evaluation Results – Model AOS-050A. ....	3-110
Table 3-34.	Load Case 101, 100°F Ambient, Maximum Decay Heat – Model AOS-050A. ....	3-112
Table 3-35.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-116
Table 3-36.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-050A. ....	3-120
Table 3-37.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-050A. ....	3-122
Table 3-38.	Load Case 105, -40°F Ambient, Maximum Decay Heat – Model AOS-050A. ....	3-124
Table 3-39.	Load Case 106, -20°F Ambient, Maximum Decay Heat – Model AOS-050A. ....	3-128
Table 3-40.	Fire Condition Thermal Evaluation Results – Model AOS-050A. ....	3-132
Table 3-41.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Model AOS-050A. ....	3-137
Table 3-42.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-141
Table 3-43.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-145
Table 3-44.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-149
Table 3-45.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-153
Table 3-46.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-050A. ....	3-157
Table 3-47.	Temperature Monitoring Points, by Condition – Model AOS-100. ....	3-162
Table 3-48.	Normal Conditions of Transport Thermal Evaluation Results – Models AOS-100A and AOS-100A-S. ....	3-164
Table 3-49.	Load Case 101, 100°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S. ....	3-166
Table 3-50.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-170
Table 3-51.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Models AOS-100A and AOS-100A-S. ....	3-174
Table 3-52.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Models AOS-100A and AOS-100A-S. ....	3-176
Table 3-53.	Load Case 105, -40°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S. ....	3-178
Table 3-54.	Load Case 106, -20°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S. ....	3-182
Table 3-55.	Fire Condition Thermal Evaluation Results – Models AOS-100A and AOS-100A-S. ....	3-186
Table 3-56.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Models AOS-100A and AOS-100A-S. ....	3-191
Table 3-57.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-195
Table 3-58.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-199
Table 3-59.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-203
Table 3-60.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-207
Table 3-61.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Models AOS-100A and AOS-100A-S. ....	3-211
Table 3-62.	Normal Conditions of Transport Thermal Evaluation Results – Model AOS-100B. ....	3-216
Table 3-63.	Load Case 101, 100°F Ambient, Maximum Decay Heat – Model AOS-100B. ....	3-217

Table 3-64.	Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-221
Table 3-65.	Load Case 103, -20°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-100B ....	3-225
Table 3-66.	Load Case 104, -40°F Ambient, Zero Decay Heat, Zero Insolation – Model AOS-100B ....	3-227
Table 3-67.	Load Case 105, -40°F Ambient, Maximum Decay Heat – Model AOS-100B .....	3-229
Table 3-68.	Load Case 106, -20°F Ambient, Maximum Decay Heat – Model AOS-100B .....	3-233
Table 3-69.	Fire Condition Thermal Evaluation Results – Model AOS-100B .....	3-237
Table 3-70.	Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat – Model AOS-100B .....	3-241
Table 3-71.	Load Case 112, Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-245
Table 3-72.	Load Case 112, Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-249
Table 3-73.	Load Case 112, Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-253
Table 3-74.	Load Case 112, Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-257
Table 3-75.	Load Case 112, Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation – Model AOS-100B .....	3-261
Table 3-76.	Summary of Heat Transfer Exact Solution Properties and their Results .....	3-267
Table 3-77.	Comparison of Heat Test GE Model 2000 and LIBRA Results .....	3-268
Table 3-78.	SS304 Stainless Steel Thermal Properties .....	3-272
Table 3-79.	Tungsten Alloy Thermal Properties .....	3-275
Table 3-80.	SA-105 Carbon Steel Thermal Properties .....	3-277
Table 3-81.	Air Properties .....	3-280
Table 3-82.	Fire Condition Impact Limiter Crushed Geometry 30-Ft. Head-On Drop Analysis Results – All Models .....	3-287
Table 3-83.	30-Ft. Drop Deformations – Model AOS-100A .....	3-299
Table 3-84.	Impact Limiter Foam Properties – Model AOS-100A .....	3-299
Table 3-85.	Compare Results Provided in Configuration 1 Versus Configuration 2, after 30 Minutes of Fire at 1,475°F – Model AOS-100A .....	3-303
Table 3-86.	Compare Results Provided in Configuration 1 Versus Configuration 2, 7.5-Hour Cool-Down Transient – Model AOS-100A .....	3-303
Table 3-87.	Compare Results Provided in Configuration 1 Versus Configuration 3, after 30 Minutes of Fire at 1,475°F – Model AOS-100A .....	3-304
Table 3-88.	Compare Results Provided in Configuration 1 Versus Configuration 3, 7.5-Hour Cool-Down Transient – Model AOS-100A .....	3-304
Table 3-89.	Total Conductivity – Model AOS-025A .....	3-312
Table 3-90.	Total Conductivity – Model AOS-050A .....	3-314
Table 3-91.	Total Conductivity – Model AOS-100A .....	3-316
Table 3-92.	Total Conductivity – Model AOS-100B .....	3-320
Table 3-93.	Maximum Grashof Number – All Models .....	3-323
Table 3-94.	Grashof Number Evaluation at All Air Gaps – Model AOS-025A .....	3-325
Table 3-95.	Grashof Number Evaluation at All Air Gaps – Model AOS-050A .....	3-326
Table 3-96.	Grashof Number Evaluation at All Air Gaps – Model AOS-100A .....	3-327
Table 3-97.	Surface Measurements and Descriptions, Normal Conditions of Transport – Model AOS-025 .....	3-328
Table 3-98.	External Convection Coefficients at 100°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025 .....	3-330
Table 3-99.	External Convection Coefficients at -20°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025 .....	3-332
Table 3-100.	External Convection Coefficients at -40°F Ambient Temperature, Normal Conditions of Transport – Model AOS-025 .....	3-334
Table 3-101.	Surface Measurements and Descriptions, Normal Conditions of Transport – Model AOS-050 .....	3-336
Table 3-102.	External Convection Coefficients at 100°F Ambient Temperature, Normal Conditions of Transport – Model AOS-050 .....	3-338
Table 3-103.	External Convection Coefficients at -20°F Ambient Temperature, Normal Conditions of Transport – Model AOS-050 .....	3-341

Table 3-104.	External Convection Coefficients at -40°F Ambient Temperature, Normal Conditions of Transport – Model AOS-050 . . . . .	3-344
Table 3-105.	Surface Measurements and Descriptions, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-347
Table 3-106.	External Convection Coefficients at 100°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-349
Table 3-107.	External Convection Coefficients at -20°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-351
Table 3-108.	External Convection Coefficients at -40°F Ambient Temperature, Normal Conditions of Transport – Models AOS-100A and AOS-100B . . . . .	3-353
Table 3-109.	Surface Measurements and Descriptions, Hypothetical Accident Conditions of Transport – Model AOS-025 . . . . .	3-355
Table 3-110.	External Convection Coefficients at 100°F Ambient Temperature, Hypothetical Accident Conditions of Transport – Model AOS-025 . . . . .	3-356
Table 3-111.	Surface Measurements and Descriptions, Hypothetical Accident Conditions of Transport – Model AOS-050 . . . . .	3-358
Table 3-112.	External Convection Coefficients at 100°F Ambient Temperature, Hypothetical Accident Conditions of Transport – Model AOS-050 . . . . .	3-360
Table 3-113.	Surface Measurements and Descriptions, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100B. . . . .	3-362
Table 3-114.	External Convection Coefficients at 100°F Ambient Temperature, Hypothetical Accident Conditions of Transport – Models AOS-100A and AOS-100B. . . . .	3-364
Table 3-115.	External Convection Coefficients at 1,475°F Environment, Fire Condition – All Models. . . . .	3-366
Table 3-116.	Plate Temperature and Length Values . . . . .	3-368
Table 3-117.	Air Property Values at 172°F. . . . .	3-368
Table 3-118.	Curved Vertical Plates Used as Flat Vertical Plate Evaluation for Thermal Condition 1 at 100°F Ambient, Maximum Decay Heat, Maximum Insolation (Load Case 102) – All Models. . . . .	3-371
Table 3-119.	Maximum Foam Temperature, 24-Hour Solar Heat Transient . . . . .	3-372
Table 3-120.	Configuration 1 and Configuration 2 Inside Plate and Cylindrical/ Conical Ring Thicknesses – All Models. . . . .	3-377
Table 3-121.	Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-025A . . . . .	3-378
Table 3-122.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-025A . . . . .	3-379
Table 3-123.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-025A . . . . .	3-379
Table 3-124.	Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-050A . . . . .	3-380
Table 3-125.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-050A . . . . .	3-381
Table 3-126.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-050A . . . . .	3-381
Table 3-127.	Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-100A . . . . .	3-382
Table 3-128.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-100A . . . . .	3-383
Table 3-129.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-100A . . . . .	3-383
Table 3-130.	Maximum Component Temperatures, Normal Conditions of Transport – Load Case 102, 100°F Ambient, Maximum Decay Heat, Maximum Insolation, Model AOS-100B . . . . .	3-384

Table 3-131.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 111, Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat, Model AOS-100B . . . . .	3-385
Table 3-132.	Maximum Component Temperatures, Hypothetical Accident Conditions of Transport – Load Case 112, 7.5-Hour Cool-Down Transient, Model AOS-100B . . . . .	3-385
Table 3-133.	Foam Density Properties – Nominal, 115% Nominal, and 85% Nominal, Model AOS-100A . . . . .	3-386
Table 3-134.	Comparison of Maximum Component Temperatures with Varying Foam Densities – Model AOS-100A . . . . .	3-387
Table 3-135.	Nominal, 115% Nominal, and 80% Nominal Foam Specific Heat Properties – Model AOS-100A . . . . .	3-388
Table 3-136.	Comparison of Maximum Component Temperatures with Varying Specific Heat Values – Model AOS-100A . . . . .	3-389
Table 3-137.	Case 1, Maximum Component Temperatures. . . . .	3-414
Table 3-138.	Case 2, Maximum Component Temperatures. . . . .	3-414
Table 3-139.	Case 3, Maximum Component Temperatures. . . . .	3-414
Table 3-140.	Case 1, Stress (psi/MPa) . . . . .	3-415
Table 3-141.	Case 2, Stress (psi/MPa) . . . . .	3-417
Table 3-142.	Case 3, Stress (psi/MPa) . . . . .	3-419

#### 4. Containment

Table 4-1.	Cask Lid Attachment Bolt Features and Properties Used for Fortran Program Input – All Models . . . . .	4-11
Table 4-2.	Cask Lid Attachment Bolt Fortran Program Results Summary – All Models . . . . .	4-16
Table 4-3.	Keensert Evaluation – Model AOS-025. . . . .	4-19
Table 4-4.	Keensert Evaluation – Model AOS-050. . . . .	4-22
Table 4-5.	Keensert Evaluation – Model AOS-100. . . . .	4-25
Table 4-6.	Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models . . . . .	4-29
Table 4-7.	Maximum Cask Cavity Pressure Due to Fire Condition – All Models . . . . .	4-29

#### 5. Shielding Evaluation

Table 5-1.	Cask Component Dimensions, Outside Radius and Half-Height – All Models . . . . .	5-2
Table 5-2.	Cask Component Dimensions, Cavity Height and Axial Shield Thickness – All Models. . . . .	5-3
Table 5-3.	Cask Component Materials Important to Shielding – All Models. . . . .	5-3
Table 5-4.	Maximum Radiation Level Summary for Normal Conditions of Transport – All Models. . . . .	5-4
Table 5-5.	Maximum Radiation Level Summary for Hypothetical Accident Conditions of Transport – All Models . . . . .	5-4
Table 5-6.	Isotopes Analyzed for AOS Transport Packages – All Models . . . . .	5-5
Table 5-7.	External Surface Deformation Used for Dose Calculation in Axial Direction – End Drop . . . . .	5-8
Table 5-8.	External Surface Deformation Used for Dose Calculation in Radial Direction – Side Drop . . . . .	5-8
Table 5-9.	Distances from Center of Cask Used for Dose Calculations – Axial Case . . . . .	5-8
Table 5-10.	Distances from Center of Cask Used for Dose Calculations – Radial Case . . . . .	5-8
Table 5-11.	Maximum Radiation Levels – Model AOS-025A . . . . .	5-17
Table 5-12.	Maximum Radiation Levels – Model AOS-050A . . . . .	5-18
Table 5-13.	Maximum Radiation Levels – Model AOS-100A and AOS-100A-S. . . . .	5-19
Table 5-14.	Maximum Radiation Levels – Model AOS-100B . . . . .	5-20
Table 5-15.	AOS Cask Isotopic Heat Loads (Reference [5.6]). . . . .	5-21
Table 5-16.	AOS Cask Isotopic Heat Load Results . . . . .	5-21
Table 5-17.	Isotope Photon per Decay – All Models . . . . .	5-22
Table 5-18.	Activation Product Gamma Spectra Used in Shielding Models – All Models . . . . .	5-22

6. Criticality Evaluation

There are no tables in Chapter 6.

7. Package Operations

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

Table 7-2. Cask Lid Attachment Bolt Size and Preload Torque – All Models..... 7-9

Table 7-3. Maximum Distance from Loaded Cask Surface to Take Surface Dose Measurements – All Models. .... 7-11

8. Acceptance Tests and Maintenance Program

Table 8-1. Acceptance Test Matrix..... 8-2

Table 8-2. Type 304 and 316 Material Requirements ..... 8-5

Table 8-3. Bolting/Screw Material Requirements ..... 8-7

Table 8-4. Casting Pipe/Casting Material Requirements (Type CPF-8, CF-8)..... 8-8

Table 8-5. LAST-A-FOAM FR-3700 Series Foams – Testing Program ..... 8-10

THIS PAGE INTENTIONALLY LEFT BLANK



# 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 1.2](#). 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 Accident 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 an isometric view of the Model AOS-025A and AOS-050A, respectively. The isometric view of the Models AOS-100A, AOS-100B and AOS-100A-S is illustrated in Figure 1-3. 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.



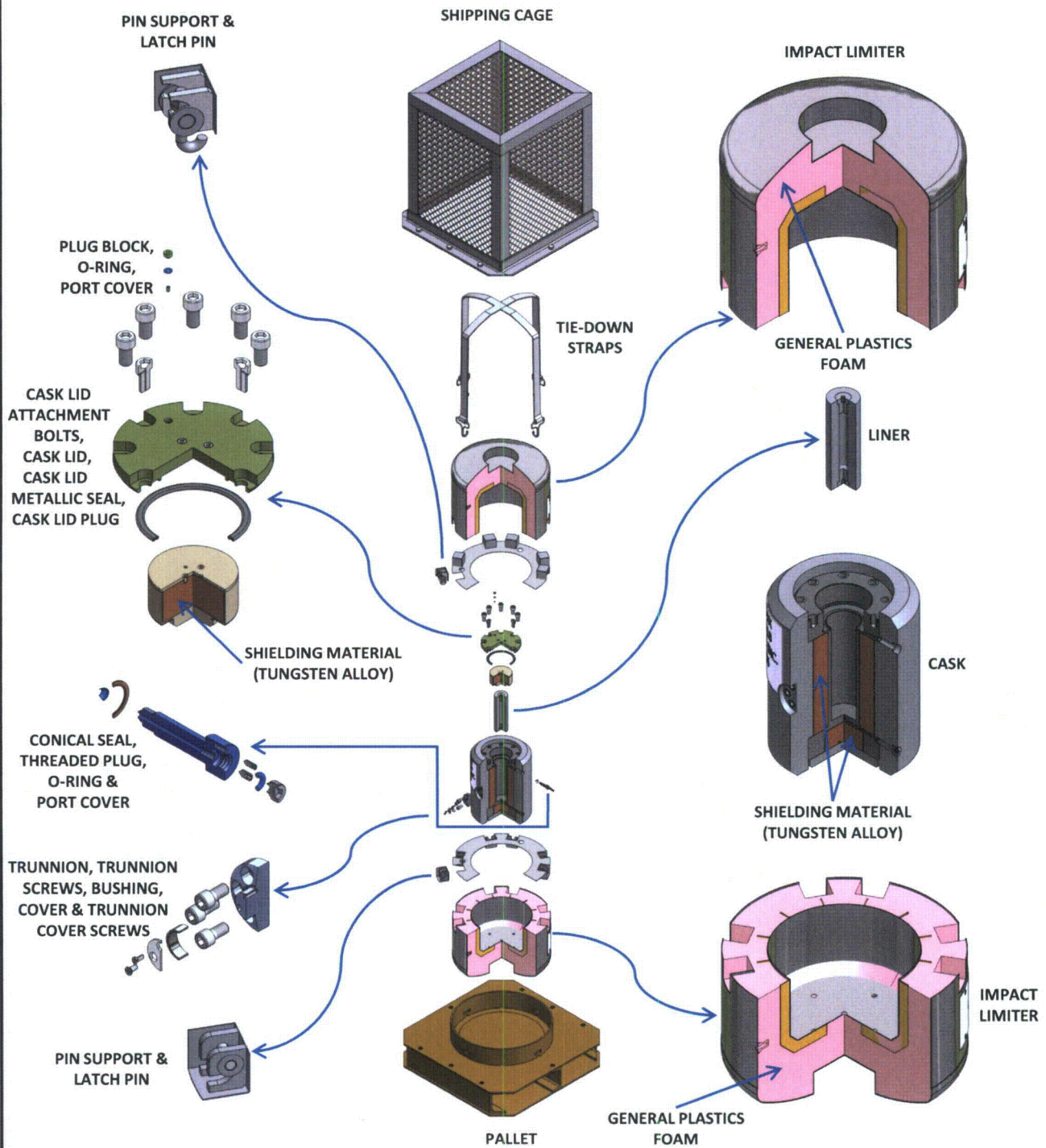


Figure 1-1. Isometric View – Model AOS-025A

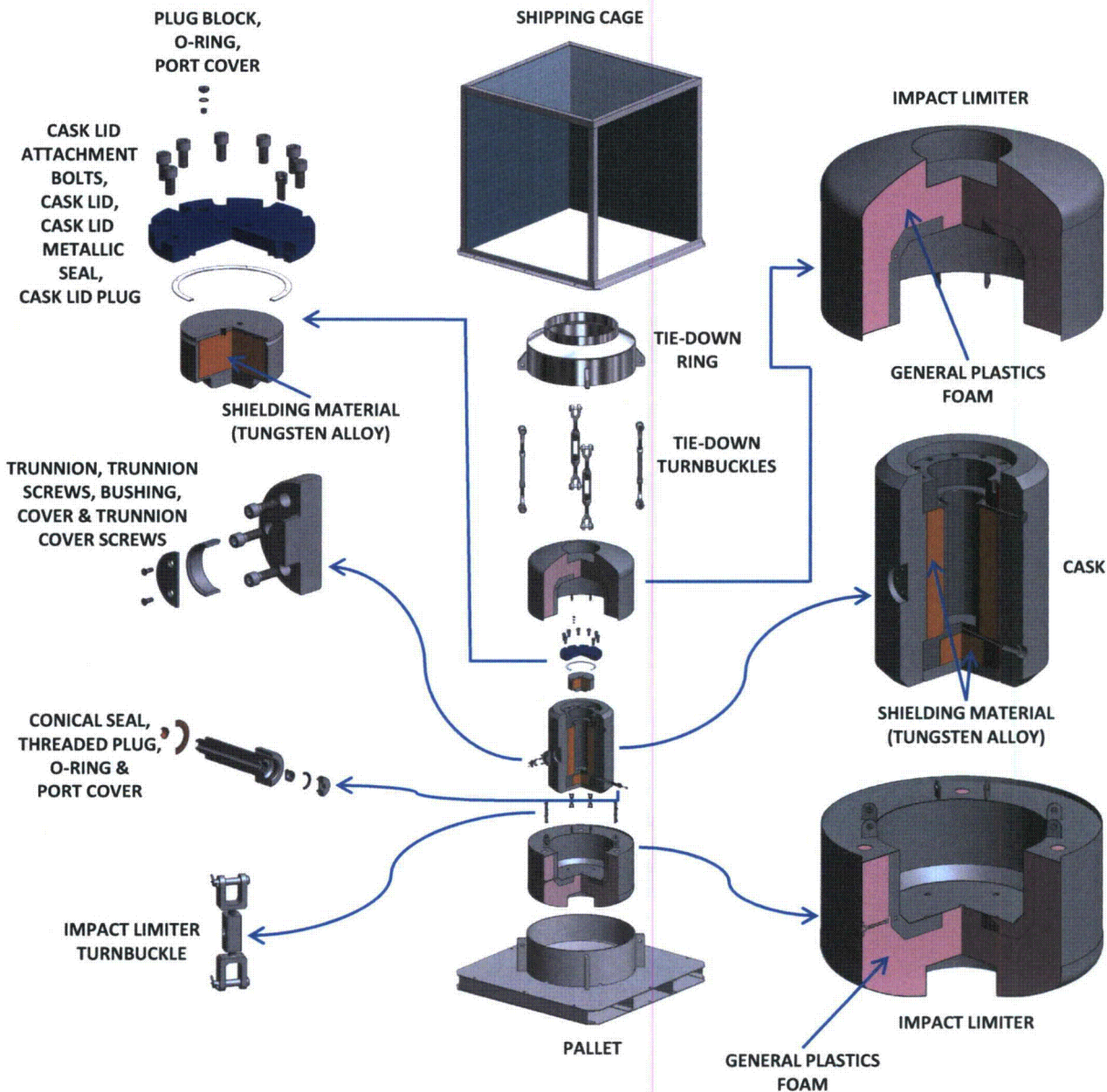


Figure 1-2. Isometric View – Model AOS-050A





## 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 inscribed as the maximum gross weight on the impact limiter identification nameplate, which is affixed to the package.

**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 <sup>a</sup> (kg / lbs.)
		Packaging		Cask		Cavity		
		OD	Height	OD	Height	OD	Height	
AOS-025A	I	28.96	41.28	17.78	22.86	4.14	12.70	100
		11.40	16.25	7.00	9.00	1.62	5.00	220
AOS-050A	I	57.99	80.21	35.56	45.72	8.26	25.40	681
		22.83	31.56	14.00	18.00	3.25	10.00	1,500
AOS-100A	I	115.93	161.44	71.12	91.44	16.51	50.80	5,675
		45.64	63.14	28.00	36.00	6.50	20.00	12,500
AOS-100B	II	115.93	161.44	71.12	91.44	16.51	50.80	4,994
		45.64	63.56	28.00	36.00	6.50	20.00	11,000
AOS-100A-S	I	115.93	161.44	71.12	91.44	16.51	50.80	5,675
		45.64	63.56	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."



## 1.2.1 Packaging

Each AOS transport package consists of three (3) main components:

- Cask
- Impact Limiter
- Cask Lid Seal

The cask is constructed of 300 series stainless steel (SS300) material. Tungsten alloy or carbon steel materials are embedded within the cask body and cask lid plug, to enhance the cask's shielding capability. Tungsten alloy is used as the shielding material in casks whose model number includes suffix A. Carbon steel is used as the shielding material in casks whose model number includes suffix B. Material designation to a national standard is provided in the certification drawings listed in [Table 1-5](#).

The solid cask outer shell, and the seal associated with the cask lid plug closure, use a double "C" cross-section seal within the cask lid joint, and provide containment under Normal and Hypothetical Accident conditions of transport. The two (2) impact limiters are connected to one another by eight (8) connectors, such that the cask ends are protected. The impact limiters are constructed of thin SS300 shells filled with polyurethane foam, which has been demonstrated to mitigate mechanical damage and thermal loads generated during Normal and Hypothetical Accident conditions of transport.

In addition to the three (3) main package components, a shipping cage and pallet ensure that accessible package surfaces are protected.

### 1.2.1.1 Cask

The cask is a cylindrical structure with a cavity that contains the payload. The cask structure is composed of seven (7) major components:

- Cask outer shell
- Cask cavity shell
- Cask shielding (tungsten alloy or carbon steel)
- Cask end plug(s)
- Bottom plate
- Cask lid
- Cask lid plug

[Figure 2-4, "Isometric View – Typical Cask,"](#) presents an isometric view of the cask.

The cask outer shell and cask cavity shell interlock, to encase the cask shielding, which is a component constructed of tungsten alloy or carbon steel.

The cask shielding and cask end plug(s) enhance the cask's shielding characteristics. To provide shielding in the axial direction, the cask lid plug is placed in the open end of the cavity. At the cavity's closed end, the cask end plug is encased between the cavity bottom wall and bottom plate. The cask end plug encased on the cask lid plug is of the same size and material (tungsten alloy or carbon steel) as the one encased at the bottom of the cask.

The cask lid consists of a flat disk, with recessed areas concentric with the bolt holes on the top surface. This feature protects the cask lid attachment bolts from impact loads. The groove on the bottom surface of the cask lid houses the cask lid metallic seal, as well as a central recess that accommodates the cask lid plug component.

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,"](#) 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, Models AOS-025A, AOS-100A, AOS-100B, and AOS-100A-S, require the use of a liner or axial shielding plate, to convey certain quantities of radioactive materials. These liners/axial shielding 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

The cask lid metallic seal consists of several components:

- **Jacket** – Silver; ASTM B742
- **Spring** – Alloy 90 UNS N07090
- **Lining** – SS304L UNS S30403 (may/may not be present)

These components are arranged in a double "C" cross-section. The seal design provides a means for leak testing between the two (2) "C" cross-sections, 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 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](#) 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 provides a list of the isotopes authorized for use with the AOS Transport Packaging System. Additionally, Table 1-2 demonstrates 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 apply, where applicable.

The AOS Transport Packaging System can be used for transporting solid radioactive materials in *Normal* and *Special form*. Any material 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.

Fissile materials and irradiated fissile materials containing fission products are not authorized for these packagings. 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 or 3,000 A<sub>2</sub>.

All shoring material within the cask cavity must have a melting point greater than 538°C (1,000°F).

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 and/or axial shielding plates) are required in certain cases, as stipulated in Table 1-2.

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, is calculated using the constants presented in Chapter 5, "Shielding Evaluation."



**Table 1-2. Activity Limits – All Models**

Isotope <sup>a</sup>	Decay Heat Ci/Watt <sup>b</sup>	Model							
		AOS-025		AOS-050		AOS-100			
		A (10W)		A (100W)		A, A-S (400W)		B (400W)	
		TBq	Ci	TBq	Ci	TBq	Ci	TBq	Ci
Co-60	6.49E+01	4.55E-03	1.23E-01	7.84E-02	2.12E+00	1.23E+02	3.33E+03	3.62E-01	9.78E+00
Co-60-B	6.49E+01	–		–		8.10E+02	2.19E+04	4.14E+00	1.12E+02
Cs-137	1.99E+02	3.92E-01	1.06E+01	1.11E+01	3.01E+02	2.95E+03	7.96E+04	1.95E+01	5.28E+02
Hf-181	2.28E+02	–		8.14E+01	2.20E+03	3.37E+03	9.12E+04	1.38E+02	3.73E+03
Ir-192	1.63E+02	2.68E+00	7.23E+01	4.77E+01	1.29E+03	2.41E+03	6.52E+04	8.58E+01	2.32E+03
Zr/Nb-95 <sup>c</sup>	6.17E+01	–		1.06E+00	2.87E+01	9.13E+02	2.47E+04	2.36E+00	6.39E+01
Ho-166	2.33E+02	4.40E-01	1.19E+01	6.55E+00	1.77E+02	–		–	
Yb-169	3.98E+02	1.47E+02	3.98E+03	1.47E+03	3.98E+04	–		–	
Shipping Configuration		Use of Liner 183C8485 is required		No additional shielding is required		Use of Axial Shielding Plates 183C8491 is required for shipment of Co-60-B quantities		Use of Axial Shielding Plates 183C8491 is required for shipment of Co-60-B quantities	

- Encapsulated solid material or solid metal that meets Normal or Special form criteria. Special form materials require a current certificate of compliance.
- For detailed calculations of these values, refer to [Appendix 5.5.1, "AOS Cask Isotopic Heat Load Calculations."](#)
- 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 1-3. Content Limitations – All Models**

Model	Type	Content <sup>a</sup>	Decay Heat		Weight <sup>b</sup>	
			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						

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

### 1.2.3 Special Requirements for Plutonium

| Not applicable. Plutonium is not an authorized content for the AOS Transport Packaging System.

### 1.2.4 Operational Features

The AOS Transport Packaging System is simple and easy-to-use. The transport packages do not incorporate any valve nor other device that allows the release or escape of the contents. Further, the package designs do not include any feature intended to allow continuous venting during transport. Positive closure for containment makes use of standard bolts and tools for opening and closing the packages. Cooling is provided by conduction and natural radiation from within the package. The seal is installed upon the cask lid and there are no alignment issues with it. Only standard practices for seal handling and use (that is, cleanliness, scratch prevention, and proper installation) are required. (For further details, refer to [Chapter 7, "Package Operations."](#))

### 1.2.5 Fabrication Codes, Standards, and Acceptance Tests

The AOS Transport Packaging System design and fabrication is controlled by the Codes, Engineering Specifications, and Standards listed in [Table 2-8, "Applicable Codes and Standards for Design, Fabrication, and Testing of the AOS Transport Packaging System."](#) In addition, [Table 2-8](#) lists the Safety Classification of all major system components, per Reference [\[1.6\]](#) guidelines.

Evaluation of the AOS Transport Packaging System, to show compliance with the applicable regulations (References [\[1.1\]](#) and [\[1.4\]](#)), is conducted by analyses, using the Finite Element Method (LIBRA Code) for all structural and thermal requirements. (For further details regarding the structural and thermal analyses and results, refer to [Chapter 2, "Structural Evaluation,"](#) and [Chapter 3, "Thermal Evaluation,"](#) respectively.)

| Shielding requirements were evaluated, primarily using the Monte Carlo N-Particle (MCNP) Code. (For further details regarding shielding evaluations, refer to [Chapter 5, "Shielding Evaluation."](#))

[Table 1-4](#) presents a summary of the engineering evaluation and analyses conducted upon each AOS Transport Packaging System model, and detailed in [Chapter 2](#) and [Chapter 3](#).



Table 1-4. AOS Transport Packaging System Analyses Summary – All Models

Item	10 CFR 71 [1.1]	IAEA TS-R-1 [1.4]	Model					Applied Conditions/Criteria
			AOS-025A	AOS-050A	AOS-100A	AOS-100B	AOS-100A-S	
<b>Package Category</b>			Table 1-1	Table 1-1	Table 1-1	Table 1-1	Table 1-1	
<b>Maximum Authorized Package Weight</b>			Table 1-1	Table 1-1	Table 1-1	Table 1-1	Table 1-1	
<b>Content</b>			Refer to Subsection 1.2.2	Refer to Subsection 1.2.2	Refer to Subsection 1.2.2	Refer to Subsection 1.2.2	Refer to Subsection 1.2.2	
<b>Physical Form (Normal or Special)</b>			Solid	Solid	Solid	Solid	Solid	
<b>Decay Heat</b>								
Activated Materials			10W	100W Isotope	400W Isotope	400W Isotope	400W Isotope	
<b>General</b>	71.33	606 – 616	✓	✓	✓	✓	✓	
Design Pressure			207 kPa (30 psia)	414 kPa (60 psia)	1,930 kPa (280 psia)	1,930 kPa (280 psia)	1,930 kPa (280 psia)	
<b>Structural</b>								
Weight and Cg			✓	✓	✓	✓	✓	
Lifting Devices	71.45(a)	607, 608	✓	✓	✓			
Tie-Down Devices	71.45(b)	612, 636	✓	✓	✓			
Containment Shell Buckling			✓	✓	✓	✓	✓	
<b>Normal Conditions of Transport</b>	71.71(c)	651						
Heat	71.71(c)(1)	653, 654, 664, 676	✓	✓	✓			38°C (100°F) shade < 50°C (122°F)

**Table 1-4. AOS Transport Packaging System Analyses Summary – All Models (Continued)**

Item	10 CFR 71 [1.1]	IAEA TS-R-1 [1.4]	Model					Applied Conditions/Criteria
			AOS-025A	AOS-050A	AOS-100A	AOS-100B	AOS-100A-S	
Differential Thermal Expansion			✓	✓	✓			
Cold	71.71(c)(2)	664, 676	✓	✓	✓			
Reduced External Pressure	71.71(c)(3)	643	✓	✓	✓			
Increased External Pressure	71.71(c)(4)		✓	✓	✓			
Vibration	71.71(c)(5)	612	✓	✓	✓			(5, 5 and 10 g's) ANSI N14.23 Draft
Water Spray	71.71(c)(6)	719, 721	✓	✓	✓			
Free Drop	71.71(c)(7)	720, 722	1.2m (4 ft.)	1.2m (4 ft.)	0.9m (3 ft.)			Solid: 0.9m (3 ft.) and 1.2m (4 ft.)
Corner Drop	71.71(c)(8)	722(b)&(c)	–	–	–	–	–	
Compression (Stacking)	71.71(c)(9)	723(a)	✓	✓	✓			5x Weight or 13 kPa (2 psi) * Projected Area
Penetration	71.71(c)(10)	724(b)	✓	✓	✓			3.2 cm (1.25 in.) and 6 kg (13 lbs.) dropped 1.7m (67 in.)

Table 1-4. AOS Transport Packaging System Analyses Summary – All Models (Continued)

Item	10 CFR 71 [1.1]	IAEA TS-R-1 [1.4]	Model					Applied Conditions/Criteria
			AOS-025A	AOS-050A	AOS-100A	AOS-100B	AOS-100A-S	
<b>Hypothetical Accident Conditions of Transport</b>	71.73(a)&(b)	726						
Free Drop	71.73(c)(1)	727(a)	✓	✓	✓			
Crush	71.73(c)(2)	727(c)	–	–	–	–	–	
Puncture	71.73(c)(3)	727(b)	✓	✓	✓			15 cm (6 in.) diameter  20 cm (8 in.) long  Distance of 1.0m (40 in.)
Thermal	71.73(c)(4)	728	✓	✓	✓			
Immersion	71.73(c)(6)	729	✓	✓	✓			150 kPa (21.7 psi)
Deep Water Immersion	71.61	730	✓	✓	✓			2 MPa (290 psia)



Table 1-4. AOS Transport Packaging System Analyses Summary – All Models (Continued)

Item	10 CFR 71 [1.1]	IAEA TS-R-1 [1.4]	Model					Applied Conditions/Criteria
			AOS-025A	AOS-050A	AOS-100A	AOS-100B	AOS-100A-S	
Thermal								
Normal Conditions of Transport								
38°C (100°F) Ambient + Decay Heat + Solar			✓	✓	✓			
38°C (100°F) Ambient + Decay Heat			✓	✓	✓			
-29°C (-20°F) Ambient + Decay Heat			✓	✓	✓			
-29°C (-20°F) Ambient			✓	✓	✓			
-40°C (-40°F) Ambient + Decay Heat			✓	✓	✓			
-40°C (-40°F) Ambient			✓	✓	✓			
Hypothetical Accident Conditions of Transport								
Fire			✓	✓	✓			
Containment								
Internal Pressure (Fission Gases)			–	–	–	–	–	
Cask Lid Joint			✓	✓	✓			
Shielding								
Source Term			✓	✓	✓	✓	✓	
Decay Heat			✓	✓	✓	✓	✓	
Gamma Dose			✓	✓	✓	✓	✓	
Transportation Index			✓	✓	✓	✓	✓	



## 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, and liner/axial shielding plates, by model.

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

Model	Assembly	Rev.	Impact Limiter	Rev.	Cask <sup>a</sup>	Rev.	Liner/Axial Shielding Plates	Rev.
AOS-025A	166D8142	E	105E9722	D	166D8143	D	183C8485	D
AOS-050A	105E9718	E	166D8138	D	166D8137	D	–	–
AOS-100A	105E9711	E	105E9713	D	105E9712G001	D	183C8491	D
AOS-100B	105E9711	E	105E9713	D	105E9712G002	D	183C8491	D
AOS-100A-S	105E9711	E	105E9713	D	105E9719	D	183C8491	D

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

THIS PAGE INTENTIONALLY LEFT BLANK



AOS Drawing No. 166D8142

Model AOS-025A Assembly

(Left Blank)

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

AOS Drawing No. 105E9722

Model AOS-025A Impact Limiter

(Left Blank)

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

AOS Drawing No. 166D8143

Model AOS-025A Cask

(Left Blank)

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

AOS Drawing No. 183C8485

Model AOS-025A Liner/Axial Shielding Plates

(Left Blank)

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

THIS PAGE INTENTIONALLY LEFT BLANK



**| 1.3.1.2      AOS Transport Packaging System Drawings – Model AOS-050A**

AOS Drawing No. 105E9718

Model AOS-050A Assembly

(Left Blank)

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

AOS Drawing No. 166D8138

Model AOS-050A Impact Limiter

(Left Blank)

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

AOS Drawing No. 166D8137

Model AOS-050A Cask

(Left Blank)

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

### **1.3.1.3**

### **AOS Transport Packaging System Drawings – Model AOS-100A, AOS-100B, and AOS-100A-S**

AOS Drawing No. 105E9711

Model AOS-100A / AOS-100B / AOS-100A-S Assembly

(Left Blank)

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

AOS Drawing No. 105E9713

Model AOS-100A / AOS-100B / AOS-100A-S Impact Limiter

(Left Blank)

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

AOS Drawing No. 105E9712G001

Model AOS-100A Cask

(Left Blank)

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



AOS Drawing No. 105E9712G002

Model AOS-100B Cask

(Left Blank)

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

AOS Drawing No. 105E9719

Model AOS-100A-S Cask

(Left Blank)

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

AOS Drawing No. 183C8491

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

(Left Blank)

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

## 1.4 REFERENCES

- [1.1] U.S. Nuclear Regulatory Commission (NRC), *Title 10, Code of Federal Regulations, Part 71 (10 CFR 71)*, "Packaging and Transportation of Radioactive Material."
- [1.2] American Society of Mechanical Engineers, *ASME Boiler and Pressure Vessel Code*, 2004 Ed., No Addendum.
- [1.3] U.S. Department of Transportation (DOT), *Title 49, Code of Federal Regulations, Part 173 (49 CFR 173)*, "Shippers – General Requirements for Shipments and Packagings."
- [1.4] *International Atomic Energy Agency (IAEA) Safety Standards Series No. TS-R-1 (IAEA TS-R-1)*, "Regulations for the Safe Transport of Radioactive Material," 1996 Ed. (as amended 2003).
- [1.5] Alpha-Omega Services, Inc. (AOS), *PR9000*, "Quality Assurance Program Radioactive Material Transport Packages," Latest.
- [1.6] McConnell, J. W. Jr., A. L. Ayers, Jr., and M. J. Tyacke, *NUREG/CR-6407, Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety*, Idaho National Engineering Laboratory, Prepared for U.S. Nuclear Regulatory Commission (NRC), February, 1996.

## 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 Accident 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.”](#)

## 2.1 DESCRIPTION OF STRUCTURAL DESIGN

### 2.1.1 Discussion

The AOS Transport Packaging System encompasses a group of transport packaging, scaled from the Model AOS-100 transport package. There are variations between models in the use of shielding materials (tungsten alloy or carbon steel), the size and number of bolts, and the density of the polyurethane foam used as a thermal shielding and energy absorbing material. The cask structure is the only true scale of the basic design, with minor variations to accommodate standard size components and/or features.

The AOS Transport Packaging System consists of three (3) main components that are important to safely operate the transport packages – cask, impact limiter, and cask lid metallic seal:

- **Cask** – The cask body, together with the cask drain port closure, cask vent port closure, and cask lid seal joint, provide containment for the radioactive contents that are stored and transported within the transport package. (Refer to [Figure 4-1, "Containment Boundary,"](#) for a depiction of the containment boundary.) The cask body 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's shielding capability. This option of shielding materials are variable within the AOS Transport Packaging System models, dependent upon the isotope being transported. Refer to [Figure 2-1](#) through [Figure 2-3](#) for cutaway views of the Model AOS-025, AOS-050, and AOS-100, packaging, respectively, and to [Figure 2-4](#) for an isometric view of a typical AOS cask.
- **Impact Limiter** – The impact limiter consists of two (2) sections, attached to one another by mechanical connectors. Each impact limiter section covers one end of the cask. The impact limiters are constructed of SS300 thin shell, filled with polyurethane foam, and mitigate mechanical and thermal loads generated during Normal and Hypothetical Accident conditions of transport. Refer to [Figure 2-5](#) for an isometric view of a typical AOS impact limiter.
- **Cask Lid Metallic Seal** – All transport package models use a metallic, double "C" cross-section seal. The cask lid metallic seal is a multiple-component assembly consisting of a nickel-chromium alloy spring and silver liner. Additional information specific to the cask lid seal is provided in [Subsection 4.1.3, "Cask Lid Metallic Seal."](#)

Refer to [Section 1.2, "Package Description,"](#) for further details regarding the packaging.

The evaluation presented here is for three (3) model sizes – AOS-025A, AOS-050A, and AOS-100A and AOS-100B. The Model AOS-100A analyses are also applicable to the Model AOS-100A-S, a double-ended configuration with a cask lid and cask lid plug at both ends, because each variation of this model effectively has the same weight.



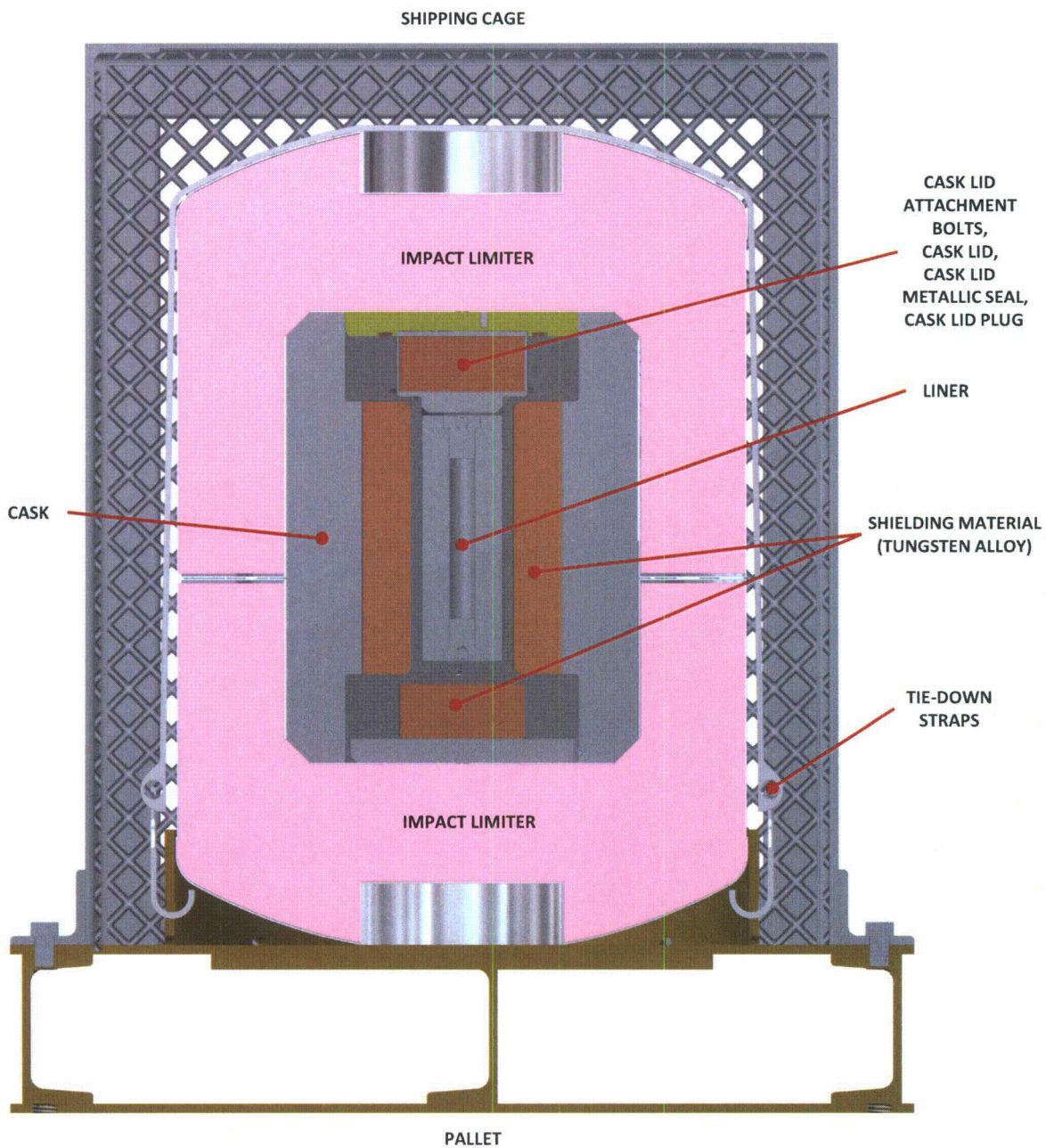


Figure 2-1. Assembled Transport Package Cutaway – Model AOS-025A



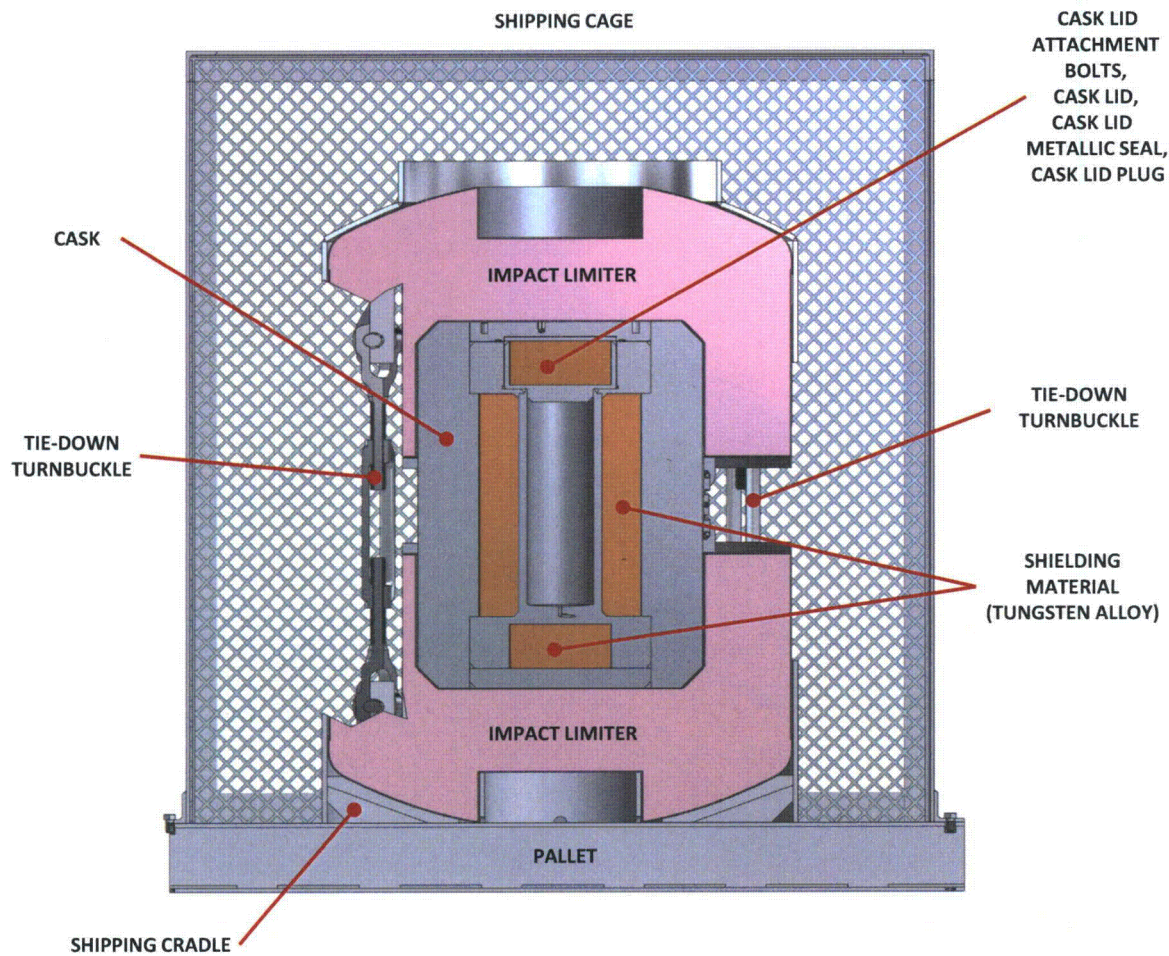
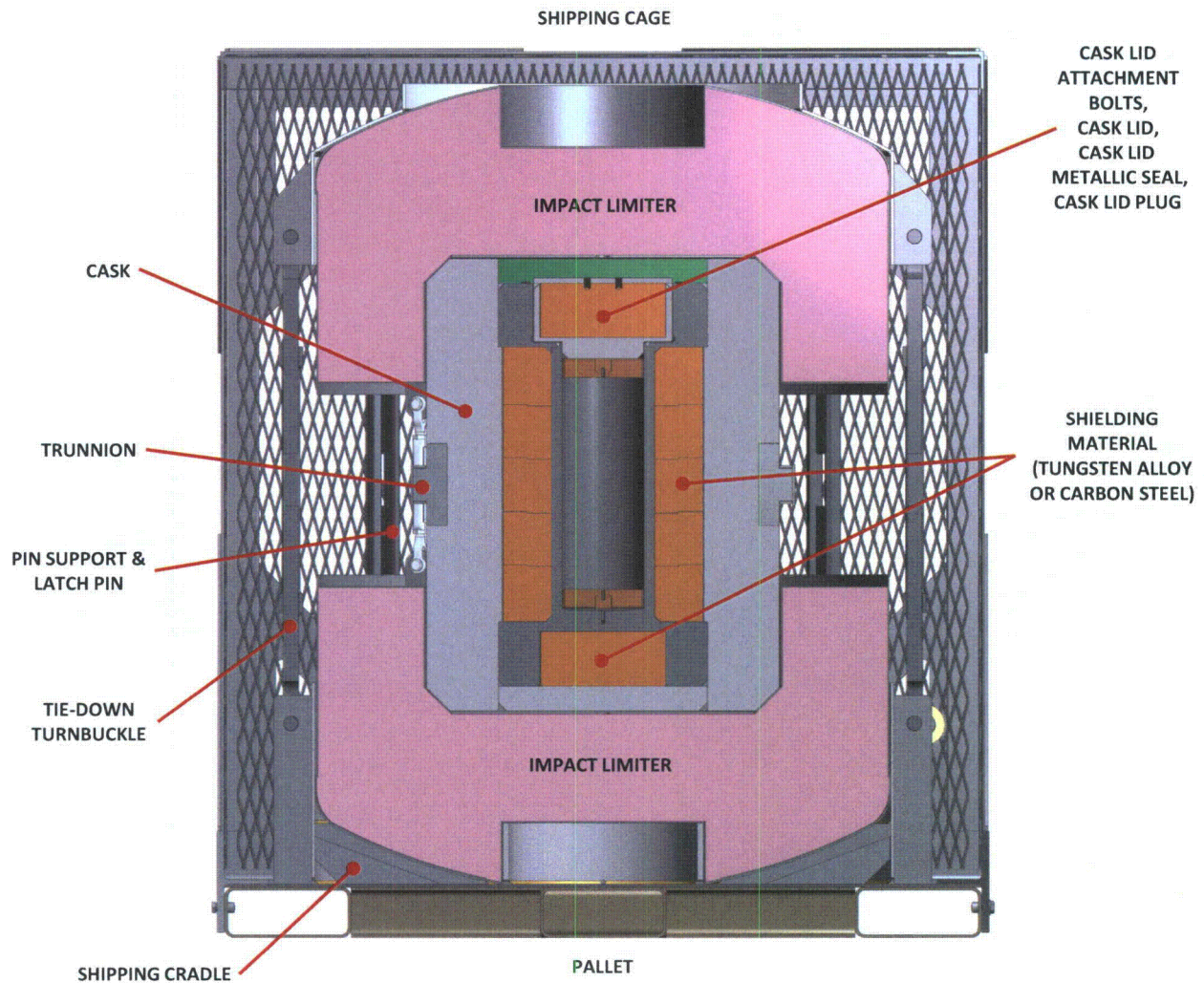


Figure 2-2. Assembled Transport Package Cutaway – Model AOS-050A



**Figure 2-3. Assembled Transport Package Cutaway – Models AOS-100A and AOS-100B**

**Note:** Model AOS-100A-S is not shown, because of its similarity to the Model AOS-100A.



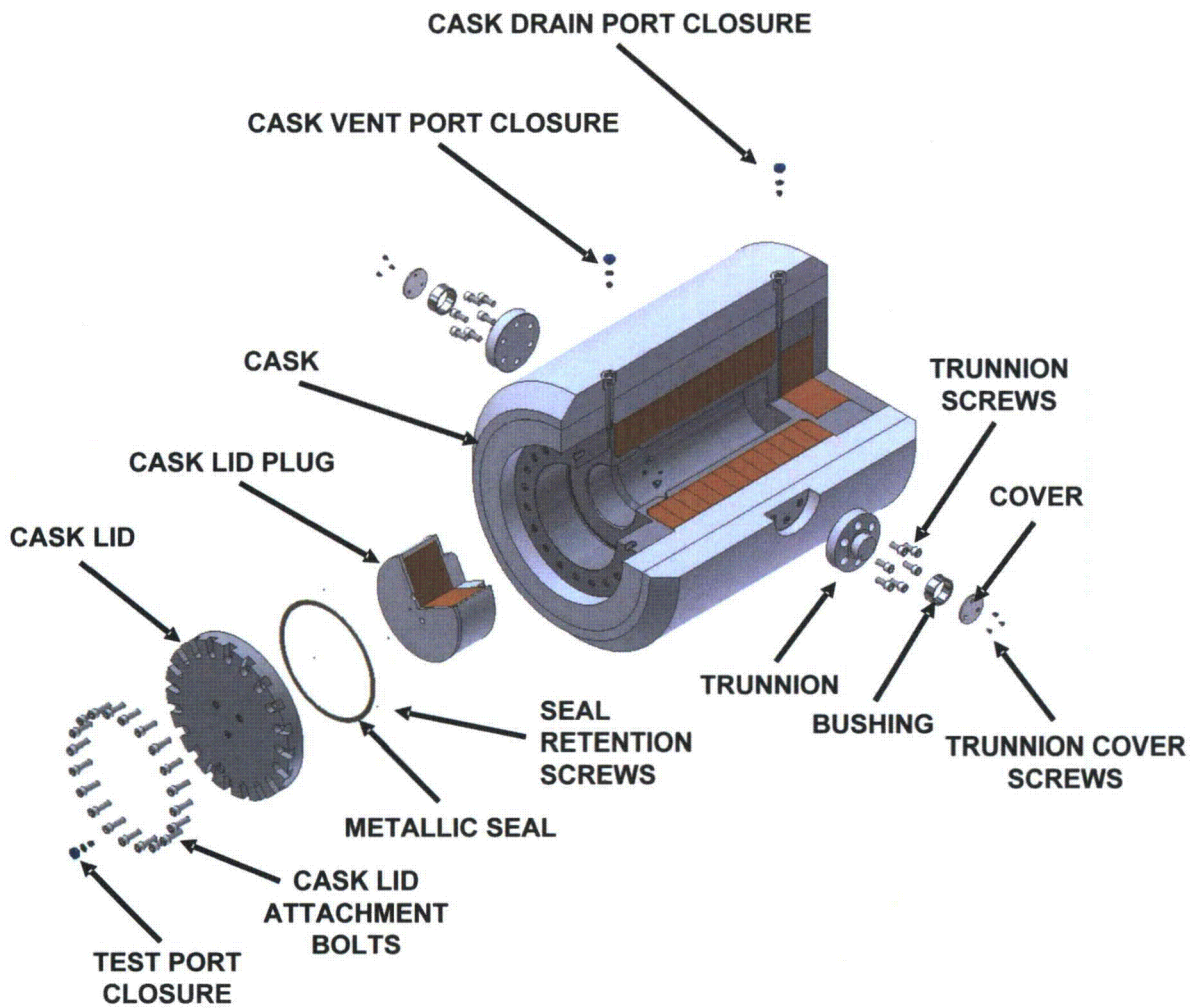


Figure 2-4. Isometric View – Typical Cask

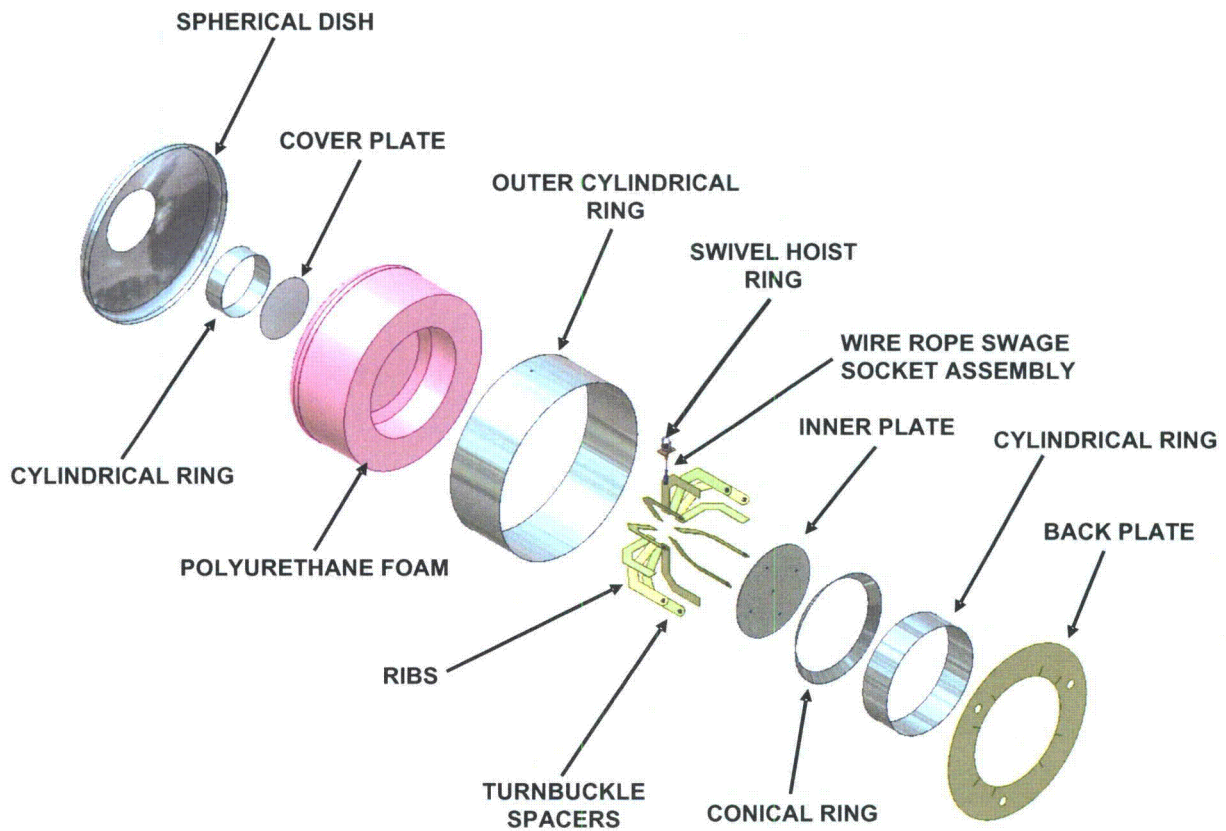


Figure 2-5. Isometric View – Typical Impact Limiter

## 2.1.2 Design Criteria

This subsection defines the allowable stress in accordance with *Regulatory Guide 7.6* (Reference [2.3]), for Load Combinations defined in *Regulatory Guide 7.8* (Reference [2.4]). Table 2-1 presents a summary of the Load Combinations for Normal and Hypothetical Accident conditions of transport, and lists the FEA models used in the evaluation. The Load Combinations presented in Table 2-1 are adapted from Reference [2.4], with some additions to reflect current regulatory requirements. The Normal and Hypothetical Accident conditions of transport design criteria for stress are obtained from Reference [2.3].

Under Normal conditions of transport, the following design criteria apply:

$$P_m < S_m$$

$$P_m + P_b < 1.5 S_m$$

$$P_m + P_b + Q < 3.0 S_m$$

Under Hypothetical Accident conditions of transport, the following design criteria apply:

$$P_m \text{ lesser of } 2.4 S_m, \text{ or } 0.7 S_u$$

$$P_m + P_b \text{ lesser of } 3.6 S_m, \text{ or } S_u$$

where:

$$S_m = \text{Allowable Primary Membrane Stress}$$

$$P_m = \text{Primary Membrane Stress}$$

$$P_b = \text{Primary Bending Stress}$$

$$Q = \text{Secondary Thermal Stress}$$

$$S_u = \text{Ultimate Stress}$$

The above criteria is consistent with Reference [2.3]. The Margin of Safety is provided by:

$$MS = (F / f) - 1.0$$

where:

$$F = \text{Allowable Stress}$$

$$f = \text{Calculated Stress}$$

[Table 2-1](#) lists the Load Combinations and other factors (Normal and Hypothetical Accident conditions of transport) that serve as design criteria. Each Normal and Hypothetical Accident condition of transport is analyzed, using various Load Combinations to demonstrate performance. Specific Load Combinations are grouped using unique designators (for example, Load Combination 101 refers to the specific combination of Ambient Temperature of 38°C, Maximum Decay Heat, Zero Insolation, and Minimum Internal Pressure). [Table 2-6](#) summarizes the Load Combinations used in the analyses.

Allowable material properties are obtained from the ASME Code (Reference [\[2.5\]](#)) for ferrous materials, and from the manufacturer's data for tungsten alloy and polyurethane foam materials. The impact load evaluation is based upon limiting the forces transferred to the cask components during the event, to a level well below the cask's capacity to safely carry the load. Each AOS Transport Packaging System model is designed for specific pressures, based upon the cavity geometry and proposed payload.

In addition to the design criteria presented above, the following failure modes are also considered:

- [Brittle Fracture](#)
- [Fatigue](#)
- [Buckling](#)

These topics are described in [Paragraph 2.1.2.1](#) through [Paragraph 2.1.2.3](#).

| Impact evaluations are provided by FEA models, as described in [Paragraph 2.1.2.4](#).

Refer to [Table 2-8](#) for a breakdown of the AOS Transport Packaging System, by component. The table  
| lists the applicable Code or Standard, as well as the applicable Safety Classification.



**Table 2-1. Summary of Load Combinations for Normal and Hypothetical Accident Conditions of Transport**

Evaluation Conditions	Load Combinations <sup>a</sup>									
	Ambient Temperature			Decay Heat		Insolation		Internal Pressure		Fabrication Stresses
	38°C (100°F)	- 29°C (-20°F)	-40°C (-40°F)	Max.	Zero	Max.	Zero	Max.	Min.	
Normal Conditions of Transport (Analyzed Individually)										
Hot Environment	101			101			101		101	211
	102			102		102		201	102	211
Cold Environment		103			103		103		103	211
			104		104		104		104	211
			105	105					105	211
		106		106					106	211
Internal Design Pressure (varies by model)	102			102		102		201		211
Reduced External Pressure – 24.5 kPa (3.5 psia)	102			102		102		202		211
Increased External Pressure – 140 kPa (20 psia)		103			103		103	203	103	211
Compression Load (5x weight)	215			101			101	201	201	211
Rod Drop onto Cask	216			101			101	201		211
	216		104		104			201		211
Vibration, Forward Load	221			102		102		201		211
	221	103			103		103		103	211
Vibration, Lateral Load	222			102		102		201		211
	222	103			103		103		103	211
Vibration, Vertical Load	223			102		102		201		211
	223	103			103		103		103	211
3- or 4-ft. Head-On Drop	231	102		102		102		201	201	211
Impact Test	232			102		102		201		211



**Table 2-1. Summary of Load Combinations for Normal and Hypothetical Accident Conditions of Transport (Continued)**

Evaluation Conditions	Load Combinations <sup>a</sup>									
	Ambient Temperature			Decay Heat		Insolation		Internal Pressure		Fabrication Stresses
	38°C (100°F)	- 29°C (-20°F)	-40°C (-40°F)	Max.	Zero	Max.	Zero	Max.	Min.	
Hypothetical Accident Conditions of Transport (Apply Sequentially)										
Free Drop										
Head-On Orientation	301			102		102		201		211
Side Orientation + Slap-Down	302			102		102		201		211
			305		104		104		104	211
Cg/Corner Orientation	303			102		102		201		211
			306		104		104		104	211
Puncture	311			101			101	201		211
Thermal										211
Fire at 30 minutes	111			102		102		201		211
Post Fire at 60, 90, 120, 150, and 180 minutes	112			102		102		201		211
Deep Water Immersion	204			101		101		201		211

a. Numbers refer to a specific Load Condition (Case). For example, Load Case 101 refers to a condition in which the environment conditions are 38°C (100°F) ambient temperature, zero (0) insolation, maximum decay heat, and zero (0) internal pressure.

### 2.1.2.1 Brittle Fracture

Brittle fracture is not considered in this evaluation, because all containment and non-containment structural components are fabricated of SS300. SS300 does not undergo ductile-to-brittle transition in the temperature range of interest [down to -40°C (-40°F)]; therefore, it is safe from brittle fracture.

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 *Section III, Division 1, paragraph NB-2311(a)(7)* in Reference [2.26].

### 2.1.2.2 Fatigue

The fatigue evaluation is limited to bolts that experience both preload shock and vibration loading during transportation. Pressurization and thermal loads do not significantly contribute to fatigue loading, because of their magnitude and long vibration period.

The allowable fatigue stress,  $S_{alt}$ , of package components corresponds to the number of vibration cycles. The design fatigue curve is provided in Reference [2.14], Section 5, Figure 1-9.2. The value of  $S_{alt}$  is corrected by the ratio of the modulus of elasticity provided on the design fatigue curve to the modulus of elasticity of the component material used in the analyses.

### 2.1.2.3 Buckling

The AOS Transport Packaging System cask shells are not likely to experience buckling instability, based upon their R/t ratio due to forces generated under Normal and Hypothetical Accident conditions of transport. However, because buckling is an unacceptable failure mode for the containment boundary (located within the cask component of the transport package), per Reference [2.3], the buckling critical force,  $F_{cr}$ , is calculated for each packaging system model, in Table 2-2.

Cask buckling under external loading requires the cask outer shell to buckle. Buckling of the cask outer shell, under compressive loading, is conservatively evaluated using the formula provided in Reference [2.6].

The reference formula for cylinder buckling under axial load is:

$$F_{cr} = k * E * t / r \quad (2-1)$$

with the coefficient  $k = 0.182$ .

The well-known solution for buckling of a cylinder under axial load [2.6] is:

$$\sigma_{CR} = [\pi^2 k_c E / 12 (1 - \nu^2)] (t / L)^2 \quad (2-2)$$

where, for moderate-length cylinders:

$$k_c = 0.702 * Z \quad (2-3)$$

$$Z = \sqrt{(1 - \nu^2) * L^2 / R * t} \quad (2-4)$$

The Z parameter in Equation 2-4 defines the cylinder length category – short, moderate, or long. The Z parameter is the same for all three (3) model sizes – AOS-025, AOS-050, and AOS-100 – because of their scale relationship:

$$Z = 14.5$$

This places the AOS cylinders in the short-to-moderate length category. For  $E = 28.0 \times 10^6$ , Equations 2-2, 2-3, and 2-4 provide:

$$k_c = 11.0$$
$$\sigma_{CR} = 6.98 \times 10^6 \text{ psi}$$



For short-to-moderate length cylinders with  $Z = 14.5$ , column buckling mode is precluded. Buckling stress under compressive load is then provided by:

$$\sigma_{CR} = 0.6 E t / R$$

(2-5)

$$\sigma_{CR} = 6.87 \times 10^6 \text{ psi}$$

The above two solutions for  $\sigma_{CR}$  demonstrate that Equation 2-1 is an alternative to Equation 2-2 for buckling stress in short-to-moderate-length cylinders. The coefficient 0.6 in Equation 2-5 is applicable to perfect cylinders – cylinders with no variation in radius and thickness. For imperfect cylinders, a smaller coefficient must be used. The value in Equation 2-1, 0.182, is applicable to thin cylinders, and is conservative for thick cylinders such as the three (3) AOS casks.

The high  $F_{cr}$  values listed in Table 2-2 preclude buckling failure.

**Table 2-2. Buckling Stress Values – All Models<sup>a</sup>**

Model	Young Module of Elasticity, E at 25.6°C (78°F) (psi) <sup>b</sup>	Wall Thickness, t (in.)	Cylinder Radius, r (in.) <sup>c</sup>	Buckling Critical Force, F <sub>cr</sub> (psi) <sup>b</sup>
AOS-025	$28 \times 10^6$	1.5	2.75	$2.78 \times 10^6$
AOS-050	$28 \times 10^6$	3.0	5.5	$2.78 \times 10^6$
AOS-100	$28 \times 10^6$	6.0	11.0	$2.78 \times 10^6$

a. The equation used for buckling stress is  $F_{cr} = 0.182 E * t / r$ .

b. Considering E at -100°F,  $29.2 \times 10^6$ , the value of  $F_{cr}$  increases by 4%.

Considering E at 600°F,  $25.3 \times 10^6$ , the value of  $F_{cr}$  decreases by 10%.

c. r is the average radius through wall thickness,  $[(\text{Outside Diameter} - \text{Inside Diameter}) / 2]$ .

#### 2.1.2.4 FEA Models

Three (3) Finite Element Analysis (FEA) analytical models are used in the stress analyses of the Model AOS-025, AOS-050, and AOS-100 transport packages – axisymmetric (2D) and 3D models of the cask component and a 3D model of the impact limiter component – for each AOS Transport Packaging System model. The cask component FEA models are used to evaluate the symmetric and non-symmetric loading condition on the cask, while the impact limiter FEA model is used to establish the free drop condition-limiting force.

The 2D model of the cask contains approximately 5,500 nodes and 5,500 elements, and is represented in [Figure 2-6](#). The 3D model of the cask contains approximately 72,700 nodes and 66,400 elements, and is represented in [Figure 2-7](#). A rendered plot of the 3D model of the cask is illustrated in [Figure 2-8](#). The 3D model of the impact limiter is presented later, in [Figure 2-32](#).

The 3D model is generated by rotation of the 2D model about the cask longitudinal axis. In this way, the 2D and 3D models are compatible for stress combinations that involve both 2D and 3D models. The 3D model is composed of 12 identical sections, over a 180° azimuth. In all 3D analyses, there is symmetry around the 0 to 180° meridian plane, requiring only a 180° model. The nodal and element numbers are defined such that adjacent meridian node and element numbers differ by 10,000. Quad and triangular elements in the 2D model are transformed into solid brick and wedge elements in the 3D model. Spring elements are preserved in the 3D model, and gaps are assumed closed in 3D analyses.

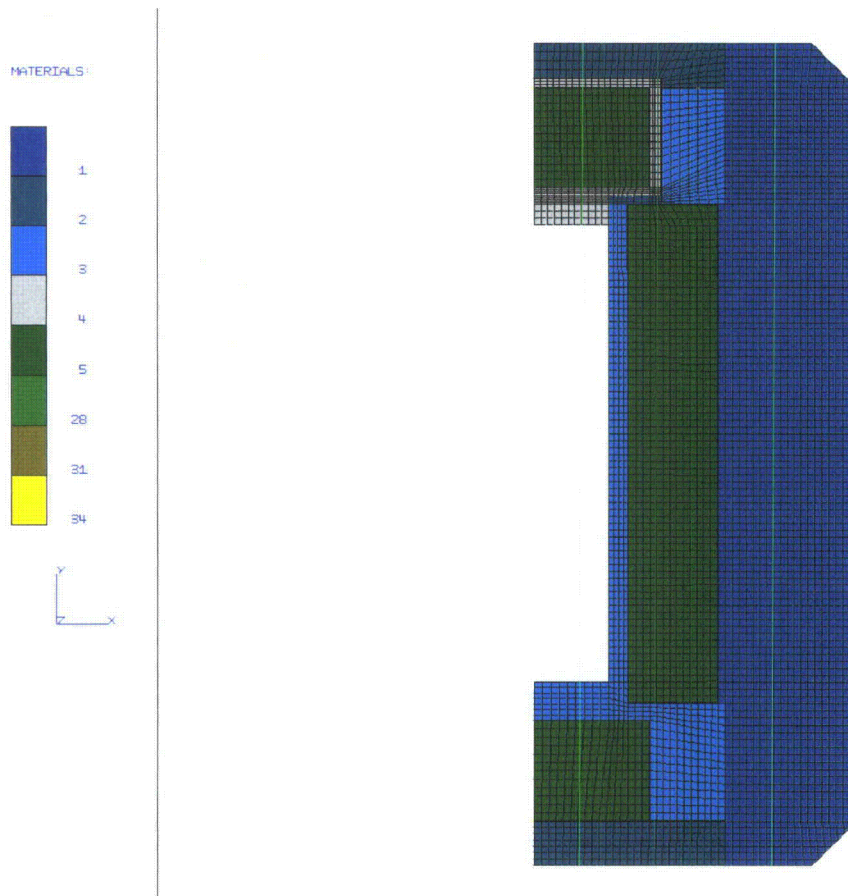


Figure 2-6. Axisymmetric (2D) Model – Models AOS-025, AOS-050, and AOS-100



MATERIALS

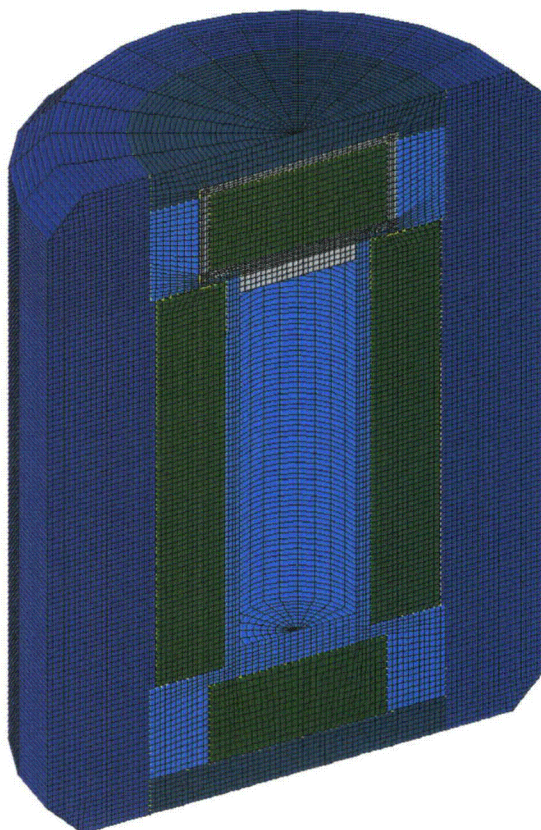
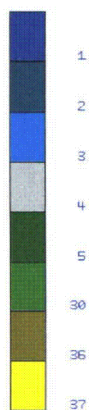


Figure 2-7. 3D Model – Models AOS-025, AOS-050, and AOS-100

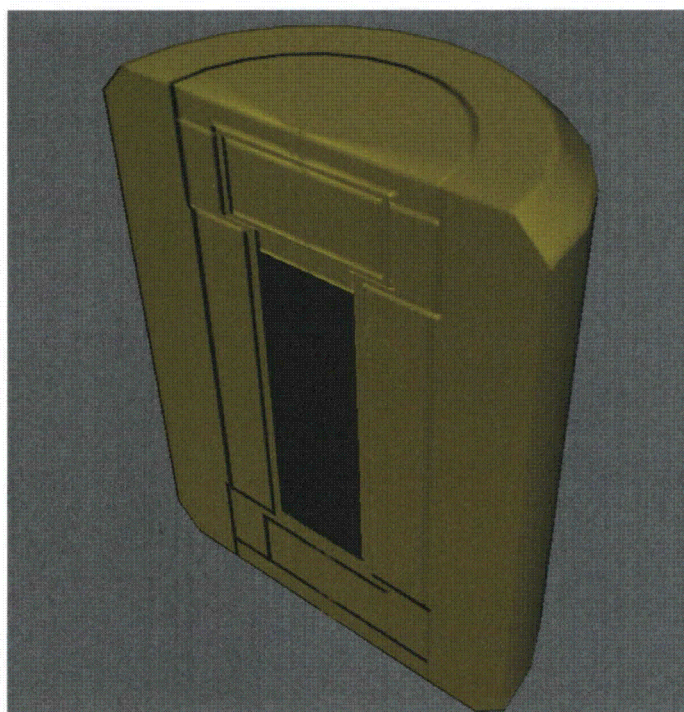


Figure 2-8. 3D Rendered Model – Models AOS-025, AOS-050, and AOS-100

### 2.1.2.4.1 Stress Monitoring Locations

The Model AOS-025, AOS-050, and AOS-100 transport packages have 22 stress monitoring locations, illustrated in Figure 2-9. Each location is a cross-section of an inside or outer shell, containing several elements. Table 2-3 lists the elements that comprise each cross-section.

Force and moment resultants at each monitored cross-section are evaluated by integrating the element stresses in the cross-section elements. In the LIBRA FEA program, element stresses are output at element Gaussian integration points, and the integrations for force and moment resultants are based upon the stress and geometry data at the gauss points. The integrated force and moment resultants are used to determine  $P_m$  and  $P_b$  stresses for the monitored cross-section.

In 3D analyses, stress is evaluated at monitoring locations in each of the 12 azimuth sections. Therefore, stresses are evaluated at 12 times (12x) the number of locations used in 2D analyses. The maximum values found in any of the 12 azimuth sections are used in forming stress combinations.

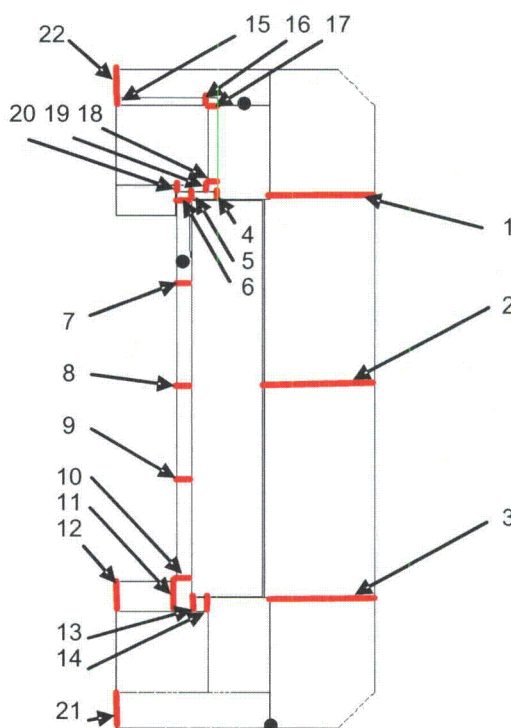


Figure 2-9.  $P_m$  and  $P_b$  Stress Monitoring Points – All Models



**Table 2-3.  $P_m$  and  $P_b$  Stress Monitoring Section Elements – All Models**

<b>Section</b>	<b>Elements</b>
1	1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155
2	552, 904, 905, 906, 907, 908, 909, 910, 911, 912, 1587, 1588, 1589, 1590, 1591, 1592, 1593, 1594, 1595, 1596
3	348, 349, 350, 351, 352, 353, 354, 355, 356, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516
4	4587, 4591, 4595, 4599
5	4572, 4575, 4578, 4581
6	4552, 4553, 4554, 4555
7	4476, 4477, 4478, 4479
8	4408, 4409, 4410, 4411
9	4344, 4345, 4346, 4347
10	4280, 4281, 4282, 4283
11	4141, 4150, 4159, 4168, 4177, 4186, 4195
12	4133, 4142, 4151, 4160, 4169, 4178, 4187
13	4212, 4215, 4218, 4221
14	4214, 4217, 4220, 4223
15	5218, 5236, 5254
16	5235, 5253, 5271
17	5214, 5215, 5216, 5217
18	5166, 5167, 5168, 5169
19	5140, 5143, 5146, 5149
20	5122, 5126, 5130, 5134
21	3001, 3017, 3033, 3049, 3065, 3081, 3097
22	3190, 3208, 3226, 3244

### 2.1.2.4.2 Load Cases and Load Combinations

Table 2-4 lists the 31 Load Cases (18 Normal, and 13 Hypothetical Accident, conditions of transport) involved in evaluating each AOS Transport Packaging System model. Each Load Case represents specific conditions of transport. Table 2-5 summarizes the numbering designations for these Load Cases. These Load Cases are then combined as "Load Combinations" in Table 2-6.

The 2D model is the predominate model used in the stress analyses of the 31 Load Cases. The 3D model is used to evaluate stress for analysis of vibration and shock loadings, as well as for Side and Cg/Corner Drop loadings.

The 31 Load Cases are combined into 34 Load Combinations (19 Normal, and 15 Hypothetical Accident, conditions of transport), listed in Table 2-6. Load Combinations numbered 100 to 299 are used for Normal conditions of transport. Load Combinations numbered 300 to 399 are used for Hypothetical Accident conditions of transport.

**Table 2-4. Load Cases**

Conditions of Transport	Load Case	Description	
Normal	101	100°F Ambient, Maximum Decay Heat	
	102	100°F Ambient, Maximum Decay Heat, Maximum Insolation	
	103	-20°F Ambient, Zero Decay Heat, Zero Insolation	
	104	-40°F Ambient, Zero Decay Heat, Zero Insolation	
	105	-40°F Ambient, Maximum Decay Heat	
	106	-20°F Ambient, Maximum Decay Heat	
	201	Internal Design Pressure • Model AOS-025 – • Model AOS-050 – • Model AOS-100 –	207 kPa (30 psia) 414 kPa (60 psia) 1,930 kPa (280 psia)
	202	Minimum External Pressure, 24 kPa (3.5 psia)	
	203	Maximum Increased External Pressure, 140 kPa (20 psia)	
	204	Additional Increased External Pressure, 2 MPa (290 psia)	
	211	Fabrication Stress	
	215	Compression Load (5x weight)	
	216	Rod Drop onto Cask	
	221	Forward 10g Vibration Inertia Load	
	222	Lateral 5g Vibration Inertia Load	
	223	Vertical 2g Vibration Inertia Load	
	231	Head-On Drop • Model AOS-025 – • Model AOS-050 – • Model AOS-100 –	4-ft. Head-On Drop 4-ft. Head-On Drop 3-ft. Head-On Drop
	232 <sup>a</sup>	30-ft. Head-On Drop Impact Test, Normal Conditions	

**Table 2-4. Load Cases (Continued)**

Conditions of Transport	Load Case	Description
Hypothetical Accident	111	Fire at 30 Minutes, 1,475°F Ambient, Maximum Decay Heat
	112	Post Fire at 60 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation
		Post Fire at 90 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation
		Post Fire at 120 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation
		Post Fire at 150 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation
		Post Fire at 180 Minutes, 100°F, Maximum Decay Heat, Maximum Insolation
	301	30-ft. Head-On Drop
	302	30-ft. Side Drop + Slap-Down
	303	30-ft. Cg/Corner Drop
	304	30-ft. Head-On Drop at -40°F, Low Temperature
	305	30-ft. Side Drop + Slap-Down at -40°F, Low Temperature
	306	30-ft. Cg/Corner Drop at -40°F, Low Temperature
	311	4-ft. Drop onto Rod

- a. Load Combination 232 is documented only for the Model AOS-025A and AOS-050A transport packages, and demonstrates compliance with the requirements of IAEA TS-R-1, Paragraph 737 (Reference [2.2]).

**Table 2-5. Load Case Designation Summary**

Conditions of Transport	Designating Number	Load Case Designation
Normal	101 to 106	Thermal Loading
	201 to 204	Pressure Loading
	211	Fabrication Stress Loading
	215	Compression Load
	216	Rod Impact Loading
	221 to 223	Vibration and Shock Loading
	231	3- or 4-ft. Drop Loading
	232 <sup>a</sup>	Impact Test, Normal Condition
Hypothetical Accident	111 and 112	Fire Accident
	301 to 306	30-ft. Accident Drop Loading
	311	4-ft. Accident Drop Loading

- a. Load Combination 232 is documented only for the Model AOS-025 and AOS-050 transport packages, and demonstrates compliance with the requirements of IAEA TS-R-1, Paragraph 737 (Reference [2.2]).

Table 2-6. Load Combinations

Conditions of Transport	Load Combination	Load Cases <sup>a</sup>	Description
Normal	101	102, 201, 211	Hot Environment
	102	104, 201, 211	Cold Environment
	103	103, 202, 211	Increased External Pressure
	104	101, 201, 202, 211	Minimum External Pressure
	105	105, 201, 202, 211	Cold Environment with Maximum Decay Heat
	106	101, 201, 203, 211	Maximum Pressure, Hot Environment
	107	105, 201, 203, 211	Maximum Pressure, Cold Environment
	215	215, 101, 201, 211	Compression Load
	216	216, 101, 201, 211	Rod Drop
	217	216, 104, 201, 211	Rod Drop, Cold Environment
	221	221, 101, 201, 211	Forward Vibration
	222	222, 101, 201, 211	Lateral Vibration
	223	223, 101, 201, 211	Vertical Vibration
	224	221, 103, 201, 211	Forward Vibration at Cold Temperature
	225	222, 103, 201, 211	Lateral Vibration at Cold Temperature
	226	223, 103, 201, 211	Vertical Vibration at Cold Temperature
	231	231, 102, 201, 211	<div>Head-On Drop, Normal Conditions</div> <ul style="list-style-type: none"> <li>Model AOS-025 – 4-ft. Head-On Drop, Normal Conditions</li> <li>Model AOS-050 – 4-ft. Head-On Drop, Normal Conditions</li> <li>Model AOS-100 – 3-ft. Head-On Drop, Normal Conditions</li> </ul>
	232 <sup>b</sup>	232, 102, 201, 211	30-ft. Head-On Drop, Normal Conditions (Impact Test)
	233	231, 103, 211	<div>Drop at Cold Temperature</div> <ul style="list-style-type: none"> <li>Model AOS-025 – 4-ft. Drop at Cold Temperature</li> <li>Model AOS-050 – 4-ft. Drop at Cold Temperature</li> <li>Model AOS-100 – 3-ft. Drop at Cold Temperature</li> </ul>



**Table 2-6. Load Combinations (Continued)**

Conditions of Transport	Load Combination	Load Cases <sup>a</sup>	Description
Hypothetical Accident	301	301, 102, 201, 211	Head-On Drop Orientation
	302	302, 102, 201, 211	Side Drop Orientation
	303	303, 102, 201, 211	Cg/Corner Drop Orientation
	304	304, 105, 202, 211	Head-On Drop Orientation at -40°F, Cold Environment
	305	305, 105, 202, 211	Side Drop Orientation at -40°F, Cold Environment
	306	306, 105, 202, 211	Cg/Corner Drop Orientation at -40°F, Cold Environment
	310	204, 101, 211	Additional Increased External Pressure (290 psi)
	311	311, 101, 201, 211	4-ft. Drop onto Rod
	312	311, 104, 201, 211	4-ft. Drop onto Rod at -40°F, Cold Environment
	350	111, 201, 211	Fire at 30 Minutes
	351	112, 201, 211	Post Fire at 60 Minutes
	352		Post Fire at 90 Minutes
	353		Post Fire at 120 Minutes
	354		Post Fire at 150 Minutes
	355		Post Fire at 180 Minutes

- a. Some Normal conditions of transport Load Cases are included in Hypothetical Accident conditions of transport Load Combinations, to meet regulatory requirements.
- b. Load Combination 232 is documented only for the Model AOS-025 and AOS-050 transport packages, and demonstrates compliance with the requirements of IAEA TS-R-1, Paragraph 737.66 (Reference [2.2]).

### 2.1.3 Weights and Centers of Gravity

Table 2-7 lists the package weight and center of gravity of each AOS Transport Packaging System model. The package is defined as the assembly of two (2) impact limiters and their mechanical connectors, the cask, and the cask contents. The content weight includes the weight of the radioactive materials, plus the weight of any shielding devices and shoring devices, if used in the assembly. The content weight excludes the weight of the shipping cage, pallet or shipping cradle, and tie-down hardware.

Figure 2-10, Figure 2-11, and Figure 2-12 illustrate the AOS Transport Packaging System center of gravity for the Model AOS-025, AOS-050, and AOS-100 transport packages, respectively.

**Table 2-7. AOS Transport Packaging System Maximum Authorized Package Weight and Cg Locations – All Models**

Model	Category	Maximum Authorized Package Weight (kg / lbs.)					Cg Locations <sup>a</sup> (cm / in.)		
		Package <sup>b</sup>	Impact Limiters <sup>c</sup>	Cask <sup>d</sup>	Contents	Pallet, Shipping Cage, and Tie-Down Devices	X	Y	Z
AOS-025A	I	100	13	64	4.5	24.9	19.05	27.18	22.86
		220	28	140	10	55	7.50	10.70	9.00
AOS-050A	I	681	56	480	27	135.2	50.5	50.5	46.0
		1,500	123	1,058	60	298	19.9	19.9	18.1
AOS-100A	I	5,675	467	3,850	227	1,685.1	77.7	77.7	79.5
		12,500	1,029	8,481	500	3,715	30.6	30.6	31.3
AOS-100B	II	4,994	467	3,192	227	1,685.1	77.7	77.7	79.5
		11,000	1,029	7,030	500	3,715	30.6	30.6	31.3
AOS-100A-S	I	5,675	467	3,850	227	1,685.1	77.7	77.7	79.5
		12,500	1,029	8,481	500	3,715	30.6	30.6	31.3

a. AOS Transport Packaging System center of gravity. Refer to Figure 2-10, Figure 2-11, and Figure 2-12 for the Model AOS-025, AOS-050, and AOS-100 transport packages, respectively.

b. Authorized package weight includes the components listed in this table; however, not all components will be at maximum weight.

c. Includes the weight of both impact limiters.

d. Includes the weight of the contents.

Figure Withheld Under 10 CFR 2.390

---

**Figure 2-10. Center of Gravity – Model AOS-025**

**Note:** *Dimensions are in inches.*



Figure Withheld Under 10 CFR 2.390

Figure 2-11. Center of Gravity – Model AOS-050

*Note: Dimensions are in inches.*

Figure Withheld Under 10 CFR 2.390

---

Figure 2-12. Center of Gravity – Model AOS-100

**Note:** *Dimensions are in inches.*

## 2.1.4 Identification of Codes and Standards for Package Design

Table 2-8 presents the applicable Codes and Standards for design, fabrication, and testing of the AOS Transport Packaging System, broken down by component category or functionality. For each category, the table addresses the applicable Code and/or Standard, as well as the Safety Classification.

**Table 2-8. Applicable Codes and Standards for Design, Fabrication, and Testing of the AOS Transport Packaging System<sup>a</sup>**

Package Components or Features	Component Safety Group									
	Containment		Criticality <sup>b</sup>	Other Safety						
	Cask Cavity Shell, Port Plugs, Threaded Pipe Plugs, Cask Lid Attachment Bolts	Cask Lid Seal	Criticality Liner	Cask Shielding (Tungsten Alloy or Carbon Steel)	Cask Outer Shell, Cask Lid Plug, Bottom Plate, Plate Shell	Port Plug Seals <sup>c</sup>	Neutron Shielding, Liner	Cask Trunnion	Tie-Down Devices	Impact Limiters
Safety Classification	A	A	A	B	B	B	B	B	B	A
B&PV Code Section	Section III, Division 1, Subsection NB		Section III, Division 1, Subsection NG	Section III, Division 1, Subsection NF						Section VIII, Division 1
Material Requirements	NB-2000		NG-2000	SAE-AMS-T-21014, Class 3	NF-2000		NF-2000	NF-2000	NF-2000	UG
Forming, Fitting, and Aligning	NB-4200		NG-4200		NF-4200		NF-4200	NF-4200	NF-4200	UG
Welding	NB-4400		NG-4400		NF-4400		NF-4400	NF-4400	NF-4400	UW
Qualification of Weld Procedure and Personnel	NB-4300		NG-4300		NF-4300		NF-4300	NF-4300	NF-4300	UW
Weld Heat Treatment	NB-4600		NG-4600		NF-4600		NF-4600	NF-4600	NF-4600	UW

Table 2-8. Applicable Codes and Standards for Design, Fabrication, and Testing of the AOS Transport Packaging System<sup>a</sup> (Continued)

Package Components or Features	Component Safety Group									
	Containment		Criticality <sup>b</sup>	Other Safety						
	Cask Cavity Shell, Port Plugs, Threaded Pipe Plugs, Cask Lid Attachment Bolts	Cask Lid Seal	Criticality Liner	Cask Shielding (Tungsten Alloy or Carbon Steel)	Cask Outer Shell, Cask Lid Plug, Bottom Plate, Plate Shell	Port Plug Seals <sup>c</sup>	Neutron Shielding, Liner	Cask Trunnion	Tie-Down Devices	Impact Limiters
Examination	NB-5000		NG-5000		NF-5000		NF-5000	NF-5000	NF-5000	UW/UG
Acceptance Testing	NB-6000	ANSI N14.5		Straight Beam method per NG-2532.1, Section III, Division 1, 2001 Edition with 2003 Addendum	Per Applicable Code Standards	ANSI N14.5		ANSI N14.6	ANSI N14.6	Per <a href="#">Table 8-1</a>

a. This table is derived from NUREG/CR-3854, Fabrication Criteria for Shipping Containers (Reference [\[2.24\]](#)).

b. Criticality does not apply to the AOS Transport Packaging System.

c. Port plug seals includes the conical seals.



## 2.2 MATERIALS

### 2.2.1 Material Properties and Specifications

As previously discussed in [Subsection 2.1.1](#), the allowable material properties used in the structural evaluation are obtained from Reference [\[2.5\]](#) for ferrous materials, and from the manufacturers' data for tungsten alloy and polyurethane foam materials.

The AOS Transport Packaging System is designed using the following materials:

- Stainless steel, 300 series (SS300; refer to the certification drawings, provided in [Appendix 1.3.1, "AOS Transport Packaging System, Certification Drawings,"](#) for applicable national material specification)
- Cask lid attachment bolts (ASME SB-637, UNS N07718)
- Tungsten alloy (Tungsten ATI Densalloy<sup>®</sup> SD180 per SAE AMS 7725D Type 2 Class 3)
- Carbon steel (Carbon Steel Forging per ASME SA-105/ASTM A105)
- Rigid, closed-cell, polyurethane foam (General Plastics, FR-3700 series)
- Trunnion screws (ASME SA-193, Grade B6 UNS S41000)

The AOS Transport Packaging System has an impact limiter component consisting of rigid, closed-cell, polyurethane foam encased by a 300 series stainless steel (SS300) shell. This energy-absorbing and temperature insulation material is a General Plastics LAST-A-FOAM<sup>®</sup> FR-3700 resin.<sup>a</sup> The impact limiter's force-deflection data, for each AOS Transport Packaging System model, is provided in [Subsection 2.7.1](#). These curves are obtained by conducting a collapsed analysis with the LIBRA Finite Element code. A complete description of the analytical procedure, as well as all testing and validation conducted to verify the procedure, are also provided in [Subsection 2.7.1](#).

[Table 2-9](#) lists the mechanical properties used for stainless steel analyses. Due to the variations in the 300 series stainless steel, the material properties used in the evaluations were chosen to be conservative. Properties selected are those of lesser values among the material choices.

[Table 2-10](#) lists the mechanical properties used for the cask lid attachment bolt analysis.

[Table 2-11](#) lists the mechanical properties used for the tungsten alloy structural and shielding analyses.

[Table 2-12](#) lists the mechanical properties used for the carbon steel shielding analysis.

[Table 2-13](#) lists the mechanical properties used for the trunnion screw analysis.

[Table 2-14](#) and [Table 2-15](#) list the mechanical properties used for the General Plastics LAST-A-FOAM FR-3700 series foam analysis.

Selected material properties are also provided in [Appendix 2.12.5, "Selected Material Properties References."](#)

---

a. FR-3700 resin is capable of producing foam with a variety of parameters, specified by contract, and verified by measurement during manufacturing.

Table 2-9. Stainless Steel Mechanical Properties (Reference [2.5])

Temperature (°F)	Module of Elasticity <sup>a</sup> , E (10 <sup>6</sup> psi)	Poisson's Ratio	Coefficient of Thermal Expansion <sup>b</sup> , $\alpha$ (10 <sup>-6</sup> in/in/°F)	Density, $\rho$ (lbm/in <sup>3</sup> )	Ultimate Tensile Stress <sup>c</sup> , S <sub>u</sub> (ksi)	Yield Stress <sup>d</sup> , S <sub>y</sub> (ksi)	Design Stress Intensity <sup>e</sup> , S <sub>m</sub> (ksi)
-20 to 100	28.3	0.30	8.6	0.29	70.0	30.0	20.0
150	—		8.8		—	26.7	—
200	27.6		8.9		66.3	25.0	20.0
250	—		9.1		—	23.6	—
300	27.0		9.2		61.8	22.4	20.0
400	26.5		9.5		59.7	20.7	18.7
500	25.8		9.7		59.2	19.4	17.4
600	25.3		9.8		59.2	18.4	16.4
650	—		9.9		59.2	18.0	16.1
700	24.8		10.0		59.2	17.6	16.0
750	—		10.0		59.0	17.2	15.5
800	24.1		10.1		58.6	16.9	15.1
850	—		10.1		57.9	16.5	—
900	23.5		10.2		56.8	16.2	—
950	—		10.3		55.4	15.9	—
1,000	22.8		10.3		53.6	15.5	—

a. Module of Elasticity, Material Group G, Table TM-1, page 671.

b. Coefficient of Thermal Expansion for Austenitic Stainless Steels (Group 3), Table TE-1, page 651.

c. Ultimate Tensile Stress, for SA-182, Grade F304, Table U, line 32, page 450.

d. Yield Stress for SA-182, Grade F304, Table Y-1, line 37, page 552.

e. Design Stress Intensity for SA-351, Grade CF8, Table 2A, line 26, page 312.



Table 2-10. Cask Lid Attachment Bolt Mechanical Properties (Reference [2.5])

Temperature (°F)	Module of Elasticity <sup>a</sup> , E (10 <sup>6</sup> psi)	Poisson's Ratio	Coefficient of Thermal Expansion <sup>b</sup> , α (10 <sup>-6</sup> in/in/°F)	Density, ρ (lbm/in <sup>3</sup> )	Ultimate Tensile Stress <sup>c</sup> , S <sub>u</sub> (ksi)	Yield Stress <sup>c</sup> , S <sub>y</sub> (ksi)	Design Stress Intensity <sup>d</sup> , S <sub>m</sub> (ksi)
-100	29.9	0.31	—	0.297	—	—	—
70	29.0		7.0		185.0	150.0	50.0
200	28.3		7.2		177.6	144.0	48.0
300	27.8		7.3		173.5	140.7	46.9
400	27.6		7.5		170.6	138.3	46.1
500	27.1		7.6		168.7	136.8	45.6
600	26.8		7.7		166.8	135.3	45.1
700	26.4		7.8		165.8	134.4	44.8
800	25.8		7.9		164.3	133.2	44.0

- a. "Module of Elasticity, Material Group B Nickel Steel," Table TM-4, page 675, ASME Code, Section II, Part D – Properties (Reference [2.5]).
- b. "Coefficient of Thermal Expansion for Material N07718," Table TE-4, page 658, ASME Code, Section II, Part D – Properties (Reference [2.5]).
- c. Ultimate Tensile Stress and Yield Stress calculated from the Stress Intensity values, provided in Table 4, Line 33, page 416, ASME Code, Section II, Part D – Properties (Reference [2.5]).

$$\frac{S_{m \text{ temp}}}{S_{m 70^\circ\text{F}}} (S_{u 70^\circ\text{F}}) = S_{u \text{ temp}}$$

- d. Stress Intensity values for Material N07718, provided in Table 4, Line 33, page 416, ASME Code, Section II, Part D – Properties (Reference [2.5]).

**Table 2-11. Tungsten Alloy Material Mechanical Properties**

Module of Elasticity <sup>a</sup> , E (10 <sup>6</sup> psi)	Poisson's Ratio <sup>b</sup>	Coefficient of Thermal Expansion <sup>c</sup> , $\alpha$ (10 <sup>-6</sup> in/in/°F)	Density <sup>a</sup> , $\rho$ (lbm/in <sup>3</sup> )	Yield Stress <sup>d</sup> , S <sub>y</sub> (ksi)
50.0	0.29	2.5	0.655	75.0

a. "Grade Specification Conformance" Table, page 16 (Reference [2.15]).

b. Chapter 6, Table 6.1, page 274 (Reference [2.18]).

c. Reference [2.17];  $\alpha = 4.6 \times 10^{-6} \text{ in/in/}^\circ\text{C} \times 5/9 = 2.5 \times 10^{-6} \text{ in/in/}^\circ\text{F}$ .

d. "Typical Densalloy Properties," page 7 (Reference [2.15]).

**Table 2-12. Carbon Steel (SA-105) Material Mechanical Properties (Reference [2.5])**

Temperature (°F)	Module of Elasticity <sup>a</sup> , E (10 <sup>6</sup> psi)	Poisson's Ratio	Coefficient of Thermal Expansion <sup>b</sup> , $\alpha$ (10 <sup>-6</sup> in/in/°F)	Density, $\rho$ (lbm/in <sup>3</sup> )	Ultimate Tensile Stress <sup>c</sup> , S <sub>u</sub> (ksi)	Yield Stress <sup>d</sup> , S <sub>y</sub> (ksi)	Design Stress Intensity <sup>e</sup> , S <sub>m</sub> (ksi)
-100	30.2	0.30	—	0.283	—	—	—
70	29.5		6.4		70.0	36.0	23.3
200	28.8		6.7		70.0	33.0	21.9
250	—		6.8		70.0	32.4	—
300	28.3		6.9		70.0	31.8	21.3
400	27.7		7.1		70.0	30.8	20.6
500	27.3		7.3		70.0	29.3	19.4
600	26.7		7.4		70.0	27.6	17.8
650	—		7.5		70.0	26.7	17.4
700	25.5		7.6		70.0	25.8	17.3
750	—		7.7		69.1	24.9	—
800	24.2		7.8		64.3	24.1	—
850	—		7.9		58.6	23.4	—
900	22.4		7.9		52.3	22.8	—
950	—		8.0		45.9	22.1	—
1,000	20.4		8.1		40.4	21.4	—

a. "Module of Elasticity, Carbon Steel with C ≤ 0.30%," Table TM-1, page 671 (Reference [2.5]).

b. "Coefficient of Thermal Expansion for Carbon and Low Alloy Steel (Group 1)," Table TE-1, page 648 (Reference [2.5]).

c. "Ultimate Tensile Stress, for SA-105, Forging," Table U, line 23, page 424 (Reference [2.5]).

d. "Yield Stress for SA-105, Forging," Table Y-1, line 26, page 500 (Reference [2.5]).

e. "Design Stress Intensity for SA-105, Forging," Table 2A, line 35, page 260 (Reference [2.5]).

Table 2-13. Trunnion Screw Mechanical Properties (Reference [2.5]) – All Models

Model	Screw Size / ASME Standard	Stress Area		Minimum Tensile Strength <sup>a</sup>		Yield Strength <sup>a</sup>	
		cm <sup>2</sup>	in <sup>2</sup>	kPa	ksi	kPa	ksi
AOS-025	1/4-28 UNF-2A / ASME SA-193, Grade B6 UNS S41000	0.235	0.036	7.58E+05	110	5.86E+05	85
AOS-050	3/8-24 UNF-2A / ASME SA-193, Grade B6 UNS S41000	0.566	0.088	7.58E+05	110	5.86E+05	85
AOS-100	3/4-16 UNF-2A / ASME SA-193, Grade B6 UNS S41000	2.406	0.373	7.58E+05	110	5.86E+05	85

a. Table 4, line 26, page 413 (Reference [2.5]).



**Table 2-14. LAST-A-FOAM FR-3700 Series Foam Dynamic Strength, psi,  
Parallel to Direction of Rise – All Models<sup>a</sup>**

<b>AOS-025 (FR-3720 20-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	1,646	1,687	1,795	1,995	2,464	3,450	4,124	5,744
-20	1,641	1,682	1,791	1,991	2,460	3,447	4,122	5,743
75	1,216	1,265	1,357	1,520	1,878	2,652	3,220	4,558
100	1,045	1,100	1,194	1,338	1,672	2,387	2,898	4,421
140	875	936	1,017	1,140	1,409	2,015	2,447	3,692
180	754	797	882	988	1,221	1,724	2,061	3,099
220	681	708	773	866	1,052	1,432	1,739	2,598
260	486	506	556	638	770	1,140	1,385	2,142
<b>AOS-050 (FR-3710 10-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	449	476	483	492	568	765	953	1,313
-20	430	461	466	474	552	753	944	1,308
75	333	339	353	367	438	588	732	955
100	290	298	314	327	394	535	666	916
140	243	254	268	283	342	459	578	802
180	217	224	236	250	302	400	497	678
220	203	203	212	224	267	347	432	582
260	150	149	162	173	210	288	358	496
<b>AOS-100 (FR-3712 12-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	640	639	661	701	832	1,120	1,413	1,837
-20	628	627	649	690	822	1,112	1,407	1,832
75	465	471	492	526	628	856	1,099	1,454
100	400	410	433	463	559	770	989	1,410
140	335	349	369	395	471	650	835	1,178
180	288	297	320	342	408	556	703	989
220	260	264	280	300	352	462	594	829
260	186	189	202	221	257	368	473	683

a. Information provided by General Plastics Manufacturing Company, Design Guide for Use of LAST-A-FOAM FR-3700 for Crash & Fire Protection of Radioactive Material Shipping Containers (Reference [2.13]).



**Table 2-15. LAST-A-FOAM FR-3700 Series Foam Dynamic Strength, psi,  
Perpendicular to Direction of Rise – All Models<sup>a</sup>**

<b>AOS-025 (FR-3720 20-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	1,626	1,680	1,786	2,012	2,439	3,407	3,958	5,301
-20	1,621	1,676	1,782	2,008	2,436	3,405	3,955	5,298
75	1,210	1,260	1,350	1,510	1,874	2,660	3,190	4,528
100	1,016	1,071	1,161	1,329	1,630	2,341	2,807	4,076
140	871	920	999	1,147	1,405	2,022	2,424	3,577
180	750	794	864	981	1,218	1,729	2,073	3,034
220	641	668	729	830	1,012	1,436	1,722	2,536
260	472	491	540	619	768	1,064	1,276	1,902
<b>AOS-050 (FR-3710 10-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	458	457	467	500	577	784	984	1,324
-20	440	441	451	483	563	774	977	1,319
75	334	326	336	366	427	582	729	970
100	284	284	296	326	384	530	663	892
140	250	251	262	289	337	460	576	776
180	210	215	229	253	294	407	503	679
220	197	193	202	223	256	349	430	582
260	150	147	158	176	205	279	350	466
<b>AOS-100 (FR-3712 12-lb. Foam)</b>								
<b>Temp (°F)</b>	<b>Strain (in./in.)</b>							
	<b>10%</b>	<b>20%</b>	<b>30%</b>	<b>40%</b>	<b>50%</b>	<b>60%</b>	<b>65%</b>	<b>70%</b>
-40	628	628	650	700	818	1,101	1,384	1,702
-20	616	616	638	688	808	1,093	1,377	1,694
75	459	463	483	518	622	854	1,110	1,448
100	386	394	416	456	541	751	977	1,303
140	331	338	358	393	466	649	844	1,144
180	285	292	309	336	404	555	722	970
220	243	245	261	285	336	461	600	811
260	179	181	193	212	255	342	444	608

a. Information provided by General Plastics Manufacturing Company, Design Guide for Use of LAST-A-FOAM FR-3700 for Crash & Fire Protection of Radioactive Material Shipping Containers (Reference [2.13]).



## 2.2.2 Chemical, Galvanic, and/or Other Reactions

Galvanic reaction occurs when two dissimilar metals with different potentials are in contact in the presence of an electrolyte. Removing or reducing these factors can decrease the possible interactions leading to a galvanic reaction. Avoiding joints using dissimilar metals, selecting joint materials that have lower potential differences, and/or eliminating the electrolyte can prevent galvanic interaction.

Table 2-16 lists the six (6) permanent dissimilar metal joints that are used within the cask component of the AOS Transport Packaging System. The joints described in Table 2-16 are shown in the certification drawings for each cask, listed in Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models."

The materials involved in joints 1, 2, 4, 5, and 6 are 300 series stainless steel and tungsten alloy or carbon steel. For joint 3, the materials are 300 series stainless steel and copper alloy. These joints are all located within the cask component of the AOS Transport Packaging System. The potential difference between stainless steel and tungsten alloy and stainless steel and copper is sufficiently low, as to not produce galvanic effects. (Refer to Reference [2.12] for potential difference information for these materials.) For the stainless steel and carbon steel joint, the carbon steel is electroless nickel-plated, with a minimum thickness of 21 microns (0.00083 in.) to reduce the different potentials.

Table 2-17 lists the four (4) temporary joints, where dissimilar metals are connected. In the case of these temporary joints, it can be said that their duration as a jointed unit, service life of their components, and continuous operational inspection preclude galvanic corrosion from occurring or going undetected.

**Table 2-16. Permanent Dissimilar Metal Joints within Cask Component**

Joint Number	Joint Description
1	Outside surfaces of the cask cavity shell, and shielding material inside diameter surfaces
2	Inside diameter surface of the cask outer shell, and outside diameter surface of the shielding material
3	Two (2) flat contact surfaces between the port and cask vent port plugs, and recessed cavity within the cask outer shell
4	Cask lid plug shell inside surface, and cask end plug
5	Cask cavity end outside recess inner surface, and cavity end plug
6	Bottom plate, and cask end plug

**Table 2-17. Temporary Dissimilar Metal Joints within Cask Component**

Joint Number	Joint Description
a	Cask lid closure joint
b	Radioactive content against its holders
c	Content holder against the shoring devices
d	Content holder or shoring device against the cask cavity surfaces

The cask's fabrication process excludes any moisture (electrolyte) from being present within the cask. During shipment (jointed unit), the cavity must be dry, regardless of how it was loaded. If the cavity was loaded in water, the cavity must be vacuum-dried. Following this procedure eliminates the presence of the electrolyte, one of the factors for galvanic interaction. Refer to [Paragraph 7.1.3.1, "Securing the Cask Lid,"](#) for the vacuum drying procedure.

Possible galvanic interaction is eliminated by controlling the potential difference for both permanent and temporary dissimilar metal joints, and by preventing the presence of an electrolyte, during fabrication and shipment.

### **2.2.3 Effects of Radiation on Materials**

The AOS Transport Packaging System's cask component is comprised of the following construction materials:

- 300 series stainless steel (SS300), tungsten alloy or low carbon steel alloy for the cask body, cask lid, and cask lid plug components
- Nickel alloy for the cask lid attachment bolts
- Silver, nickel chromium, and stainless steel for the cask lid metallic seal
- Silicone material for the port cover O-Rings

Of all these materials, the one most affected by radiation is the silicone material. However, these port cover O-Ring components are replaced after each use, thus eliminating the cumulative effect of radiation.

The impact limiters are constructed of 300 series stainless steel and polyurethane foam materials. The effect of radiation upon the stainless steel material is minimal. Also, according the manufacturer's data for the polyurethane foam (Reference [\[2.13\]](#)), its material does not incur any physical property changes when subjected to a maximum cumulative dose of  $2 \times 10^8$  rads. Therefore, the impact limiters are not affected by radiation.

## 2.3 FABRICATION AND EXAMINATION

### 2.3.1 Fabrication

This subsection describes the fabrication processes used for the AOS Transport Packaging System, such as fitting, aligning, welding and brazing, heat treatment, and foam pouring. [Table 2-8](#) provides a breakdown of the AOS Transport Packaging System by category of functionally, the corresponding applicable Code and/or Standard, and the Safety Classification. The information provided in [Table 2-8](#) follows the guidelines presented in *NUREG/CR-3854, Fabrication Criteria for Shipping Containers*, and *NUREG/CR-3019, Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials* (References [\[2.24\]](#) and [\[2.25\]](#), respectively).

[Table 2-18](#) lists the material selection specifications for the major components used in the AOS Transport Packaging System.

**Table 2-18. Material Selection of Major AOS Transport Packaging System Components (Typical)**

Component	Material Selection	First Alternate Material	Second Alternate Material	Certification Drawing <sup>a</sup>	Item No.
Cask					
Cask Outer Shell	ASME SA-182/ ASTM A182, Grade F304 or F316	ASME SA-351/ ASTM A351, Grade CF 8	ASME SA-451/ ASTM A451, Grade CPF 8	105E9712	1
Cask Lid	ASME SA-240/ ASTM A240, Type 304 or 316	ASME SA-182/ ASTM A182, Grade F304 or F316	–		2
Cask Cavity Shell	ASME SA-182/ ASTM A182, Grade F304 or F316	ASME SA-351/ ASTM A351, Grade CF 8	ASME SA-451/ ASTM A451, Grade CPF 8		3
Shielding Material	Tungsten ATI Densalloy SD180 per SAE AMS 7725D Type 2 Class 3	Carbon Steel Forging per ASME SA-105/ ASTM A105	–		4, 8, 12
Trunnion	ASME SA-479/ ASTM A479, Type 304 or 316	–	–		5
Cask Lid Plug	ASME SA-240/ ASTM A240, Type 304 or 316	ASME SA-182/ ASTM A182, Grade F304 or F316	–		6
Cover Plate	ASME SA-240/ ASTM A240, Type 304 or 316	ASME SA-182/ ASTM A182, Grade F304 or F316	–		7
Cask Lid Attachment Bolts	ASME SB-637, UNS N07718	–	–		15
Bottom Plate	ASME SA-240/ ASTM A240, Type 304 or 316	ASME SA-182/ ASTM A182, Grade F304 or F316	–		16
Trunnion Screws	ASME SA-193, Grade B6 UNS S41000	–	–		24
Port Plug	ASME SA-182/ ASTM A182, Grade F304 or F316	ASME SA-479/ ASTM A479, Type 304 or 316	–	32	
Impact Limiter					
Shell and Ribs	ASME SA-240/ ASTM A240, Type 304 or 316	–	–	105E9713	1 – 11
Foam	Polyurethane Foam (General Plastics FR-3700 Series Foams)	–	–		12

a. The Model AOS-100A certification drawings are used for the **Item No.** (column) references for completeness of the table information.



### **2.3.1.1 Materials**

- Materials are procured by the Fabricator from material manufacturers or suppliers that have been audited and approved by the Fabricator, under their approved Quality Plan.
- Materials are in accordance with the applicable rules of ASME Section II Parts A, B, and C, as applicable; ASME Section III NCA-3800; Heat treatment of new material is controlled by the material procurement procedure and Quality Plan.
- Material purchased requiring upgrading (ASME) or commercial grade dedication uses procedures and/or checklists approved in accordance with the Fabricator's approved Quality Plan.
- Material certification is approved prior to final acceptance of the material.
- Deviations and non-conformances relating to the material are dispositioned by a written procedure as specified in the Fabricator's Quality Plan, prior to material acceptance.

### **2.3.1.2 Fabrication**

- Fabrication is conducted by the Fabricator, in accordance with established, written process documentation (travelers, bills of material, weld maps, inspection and test reports), and using written procedures for processes.
- Process documentation provides for the identification and control of all materials to be used in the fabrication process of components and assembly. Material is identified and recorded on the appropriate process documents. The process documentation provides for "hold points," to allow for critical verifications by the purchaser.

### **2.3.1.3 Forming**

- Forming has limited use in the fabrication of the AOS Transport Packaging System. It may be used in producing the impact limiter heads and shells.

### **2.3.1.4 Machining**

- Forgings, plates, and round bars (purchased in the "stock-on" condition) are machined to established dimensional configurations, as identified on the drawings, and delineated by the Fabricator's process documentation. The dimensional configurations established allow for fitting and alignment of the components that are part of components, sub-assemblies, and assemblies.
- Welded components are final machined to established dimensional configurations, as identified on the drawings, and delineated by the Fabricator's process documentation.
- Those components that are not a part of the assembly (cask lid, trunnions, and trunnion details) are machined to final configuration as identified on the drawings, and delineated by the Fabricator's process documentation.

### **2.3.1.5 Fitting and Assembling**

- Components of the AOS Transport Packaging System are fitted and assembled in accordance with the Fabricator's process documentation. Recording of the completion of work is maintained in the process documents.
- Alignment of sections to be joined by welding is controlled in accordance with the Fabricator's process documentation and the applicable drawings.



### **2.3.1.6 Welding**

- These welding processes can be used in the fabrication of the AOS Transport Packaging System – Shielded Metal Arc Welding (SMAW), Flux Cored Arc Welding (FCAW), Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW) Submerged Arc Welding (SAW) or Plasma-Transferred Arc Welding (PTAW). Additional American Welding Society (AWS) welding processes can also be used.
- Welding Procedure Specifications (WPSs) are in accordance with ASME Section IX requirements, and supplemented as required by ASME Section III NF/NG-4330.
- Qualified welders assigned by the Fabricator must conduct all welding activities.
- Welder Qualification records are in accordance with ASME B&PV Code Section III NF/NG-4320, and are on file at the Fabricator's location.

### **2.3.1.7 Heat Treating**

- There are no heat treating requirements for the AOS Transport Packaging System, with the exception of heat treatment conducted, where required, by applicable material specifications.

## 2.3.2 Examination

Table 2-19 summarizes the AOS Transport Packaging System examination program. Additional detailed information is provided in Chapter 8, "Acceptance Tests and Maintenance Program."

**Table 2-19. Examination Program Summary**

Test Category	Test Type	Reference	Test Description
<b>Materials</b>			
Stainless Steel	Certified Material Test Report	ASME Code, Section II, Part A, and applicable requirements of NX-2500, Section III.	Series of chemical and mechanical tests to determine conformance with material specification.
Tungsten Alloy	Density Verification	Straight Beam method per NG-2532.1, Section III, Division 1, 2001 Edition with 2003 Addendum.	One UT examination of the material surfaces and calculating the resulting component density by weighing and dimensionally inspecting the component, to determine its volume.
Foam	Formulation Verification	Table 8-5, "LAST-A-FOAM FR-3700 Series Foams – Testing Program."	Series of tests to establish the material characteristics baseline.
<b>Fabrication</b>			
Component	Adherence to Drawing	Certification Drawings. Refer to Table 1-5, "AOS Transport Packaging System Certification Drawing List – All Models."	Visual and Dimensional inspections.
Sub-assembly			
Assembly	Pressure and Containment	ASME Code, Section V, and applicable requirements of NB-6000, Section III.	Hydrostatic and He Leak test.
Weldment	NDE	ASME Code, Section V, and applicable requirements of NX-5000, Section III.	Visual, Penetrant, and Ultrasonic tests (VT, PT, and UT, respectively).

## **2.4 GENERAL REQUIREMENTS FOR ALL PACKAGES**

### **2.4.1 Minimum Package Size**

All AOS Transport Packaging System model dimensions are greater than 10 cm (4 in.), and therefore exceed minimum package size requirements.

### **2.4.2 Tamper-Indicating Feature**

A tamper-indication feature, installed across the impact limiter joint section, provides evidence of unauthorized tampering. With the package assembled for transportation and the impact limiter installed, there are no additional covers, ports, nor other accesses that must be closed during Normal conditions of transport. Refer to [Paragraph 7.1.3.4, "Preparing the Cask for Transport of Radioactive Material,"](#) for further details.

### **2.4.3 Positive Closure**

The AOS Transport Packaging System models are used for shipping radioactive materials within the cask component. The first level of closure of the cask cavity is provided by the cask lid joint. The cask cavity shell consists of two SS300 series forgings, machined to form and joined together by a full-penetration weld. The cask lid joint consists of the cask lid, a cask lid metallic seal, and a series of cask lid attachment bolts. The bolts are tightened to a prescribed torque value. There are two (2) other penetration points into the cavity. The port plugs are threaded into the cask cavity and welded onto the outside to the cask outer shell. Copper seals, located at both ends of the port plugs, ensure the leak tightness of these joints. The port plug conduits are closed and sealed by pipe plugs and straight thread caps with silicone O-Rings.

## 2.5 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

The following information is presented:

- Lifting Devices
- Tie-Down Devices
- Other Devices

### 2.5.1 Lifting Devices

10 CFR 71.45(a) [2.1] requires that lifting devices that are a structural part of the transport package must be capable of supporting three times the weight ( $3W$ ) of the loaded package, without generating stress in any material of the package in excess of its yield stress.

Figure 2-13 presents a cross-section of the trunnion area, as well as the force diagram associated with the lifting loads. The dimensions for the figure are listed in Table 2-20.

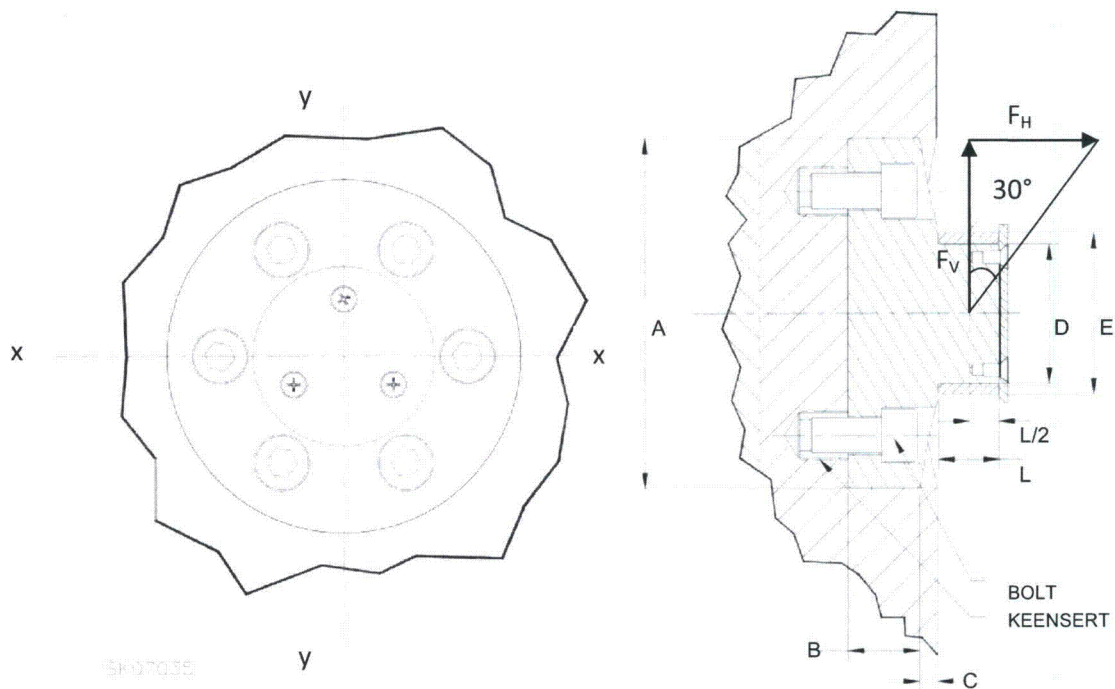


Figure 2-13. Trunnion Area Cross-Section and Force Diagram Associated with Lifting Loads

### 2.5.1.1 Cask Lifting Analysis – Trunnion Screw Evaluation

The vertical force,  $F_V$ , applied to each trunnion is defined as:

$$F_V = (\text{DLF} * 3 * \text{package weight}) / 2$$

where:

$$\begin{aligned} \text{DLF} &= \text{Dynamic Load Factor} \\ &= 1.2 \end{aligned}$$

The horizontal force,  $F_H$ , is defined as:

$$F_H = F_V * \tan 30^\circ$$

Moment about trunnion screw x-axis is:

$$M_x = F_V * [B + C + L/2]$$

Tensile force in trunnion screw furthest away from trunnion screw centroid about x-axis due to moment:

$$F_b = (M_x * C_L) / I_{x-x}$$

where:

$$I_{x-x} = \sum (r_y)^2$$

Tensile force in each trunnion screw due to horizontal force:

$$F_t = F_H / 6$$

Maximum total trunnion screw tensile stress is:

$$S_t = (F_b + F_t) / A_{\text{tensile}}$$

Trunnion screw preload stress:

$$S_{\text{preload}} = \text{Pre-torque} / (0.2 * D_{\text{nominal}} * A_{\text{tensile}})$$

Margin of safety is defined as:

$$\text{MS} = (S_y / S_t) - 1.0$$



Table 2-20. Lifting Load Analysis – All Models

Item	Units		Model					
			AOS-025		AOS-050		AOS-100	
			Metric	English	Metric	English	Metric	English
Weight	kg	lbs.	76	168	536	1,181	4,314	9,510
A	cm	in.	4.14	1.63	8.26	3.25	16.51	6.50
B	cm	in.	0.84	0.33	1.65	0.65	3.30	1.30
C	cm	in.	0.19	0.08	0.41	0.16	0.84	0.33
D	cm	in.	1.65	0.65	3.30	1.30	6.60	2.60
E	cm	in.	1.91	0.75	3.81	1.50	7.65	3.01
L	cm	in.	0.71	0.28	1.45	0.57	2.69	1.06
L/2	cm	in.	0.36	0.14	0.72	0.29	1.35	0.53
F <sub>T</sub>	N	lbf.	1,553	349	10,919	2,455	87,924	19,766
F <sub>H</sub>	N	lbf.	777	175	5,459	1,227	43,962	9,883
F <sub>V</sub>	N	lbf.	1,345	302	9,456	2,126	76,145	17,118
Trunnion Screw Size			1/4-28 UNF - 2A × 0.5L		3/8 - 24 UNF - 2A × 0.75L		3/4 - 16 UNF- 2A × 1.50L	
Material			ASME SA-193, Grade B6 UNS S41000		ASME SA-193, Grade B6 UNS S41000		ASME SA-193, Grade B6 UNS S41000	
Pre-Torque	Nm	lbf-ft.	16	12	47	35	407	300
Bolt Circle	cm	in.	2.90	1.14	5.77	2.27	10.80	4.25
S <sub>u</sub>	MPa	ksi	7.58E+02	1.10E+02	7.58E+02	1.10E+02	7.58E+02	1.10E+02
S <sub>y</sub>	Pa	psi	5.86E+08	8.50E+04	5.86E+08	8.50E+04	5.86E+08	8.50E+04
Quantity			6		6		6	
Keensert			KNH 428J		KNH 624J		KNH 1216J	
			1/4-28UNF-3B × 0.37		3/8-24UNF-3B × 0.50		3/4-16UNF-3B × 1.12	
D <sub>nominal</sub>	cm	in.	0.64	0.25	0.95	0.38	1.91	0.75
A <sub>tensile</sub>	cm <sup>2</sup>	in <sup>2</sup>	0.23	0.036	0.57	0.088	2.41	0.373
M <sub>x</sub>	Nm	lbf-in.	19	165	263	2,328	4,178	36,975
C <sub>L</sub>	cm	in.	1.25	0.49	2.50	0.98	4.67	1.84
I <sub>x-x</sub>	cm <sup>4</sup>	in <sup>4</sup>	6.29E+00	9.75E-01	2.49E+01	3.86E+00	8.74E+01	1.35E+01
F <sub>b</sub>	N	lbf.	3.72E+02	8.36E+01	2.63E+03	5.92E+02	2.23E+04	5.02E+03
F <sub>t</sub>	N	lbf.	1.29E+02	2.91E+01	9.10E+02	2.05E+02	7.33E+03	1.65E+03
S <sub>t</sub>	Pa	psi	2.13E+07	3.10E+03	6.26E+07	9.07E+03	1.23E+08	1.79E+04
S <sub>preload</sub>	Pa	psi	5.46E+08	7.91E+04	4.40E+08	6.38E+04	4.44E+08	6.43E+04
MS = (S <sub>y</sub> / S <sub>t</sub> ) - 1.0			26.46		8.37		3.75	

### 2.5.1.2 Cask Socket Bearing Stress Check

The bearing area, as illustrated in [Figure 2-13](#), is:

$$\text{Area} = A * B$$

where:

A and B are provided in [Table 2-20](#).

The ultimate stress for the cask material is 70 ksi.

Margin of safety is defined as:

$$MS = (S_u / S_t) - 1.0$$

[Table 2-21](#) lists the average bearing stress.

**Table 2-21. Average Bearing Stress – All Models**

Model	Force, $F_v$ (lbf.)	Area (in <sup>2</sup> )	Stress (psi)	Margin
AOS-025	302	0.54	559	124.2
AOS-050	2,126	2.11	1,008	68.4
AOS-100	17,118	8.45	2,026	33.6

### 2.5.1.3 Shear Stress at Trunnion Neck

The maximum shear stress for a circular section is:

$$S_V = (4 * F_V) / (3 * A)$$

Yield stress in shear is 0.58 times the tensile yield stress. Then,  $S_y = 17.4$  ksi.

Margin of safety is defined as:

$$MS = (S_y / S_t) - 1.0$$

Table 2-22 lists the maximum shear stresses.

Lifting device margins of safety, in all transport package models, are greater than 3.0. The neck of the trunnion has the lowest margin of safety. Should failure occur in the trunnion neck, no damage to the transport package will occur.

**Table 2-22. Maximum Shear Stress,  $S_V$  – All Models**

Model	Force, $F_V$ (lbf.)	Area (in <sup>2</sup> )	Stress (psi)	Margin
AOS-025	302	0.33	1,220	13.26
AOS-050	2,126	1.33	2,131	7.17
AOS-100	17,118	5.31	4,298	3.05



## 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 1-3](#) 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 Shield Plate – Model AOS-100](#)
  - [Stress Analysis of Cavity Liner – Model AOS-025](#)

### 2.5.3.1 Analyses of Shipping Cage and Shipping Cage Fasteners

#### 2.5.3.1.1 Stress Analysis of Shipping Cages

The combination of shipping cage wire mesh panels and angle x-section frame behaves as a Tension Field Beam. In Tension Field Beams, web panels are assumed to buckle upon load application, and shear forces,  $V$ , are transmitted by web tension stress,  $\sigma_t$  [2.9]. The wire mesh behaves as an ideal Tension Field web panel, because wire mesh can transmit only tension stress. Panel dimensions used in the analysis are larger than actual dimensions, to accommodate possible changes. Use of larger panel dimensions is conservative. Additionally, the shipping cage design used in the evaluation is a more simple design than the actual design, making the analysis conservative.

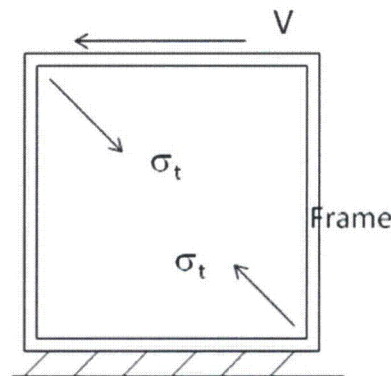


Figure 2-14. Mesh Diagonal Tension

The web thickness equivalent to the wire mesh is determined using Reference [2.10]. For the AOS Transport Packaging System, the shipping cage mesh size corresponds, approximately, to the 22 × 60 mm steel mesh in Reference [2.10]. From Reference [2.10], this mesh weight is:

$$w = 3.69 \text{ kg/m}^2 = 0.00525 \text{ lb/in}^2$$

The equivalent web thickness for steel with density  $\rho = 0.28 \text{ lb/in}^3$  is then:

$$t_w = w / \rho = 0.00525 / 0.28 = 0.019 \text{ in.}$$

From Reference [2.9], with  $f_t$  and  $f_s$  web tension and shear stress resultants, and  $\alpha$  the web diagonal tension angle:

$$f_t = 2 * f_s / \sin 2\alpha$$

$$\alpha = 45^\circ$$

$$f_t = 2 * f_s$$



Web strain energy due to tension stress,  $\sigma_t$ , is:

$$U = (1/2) (\sigma_t)^2 (A_w * t_w) / E$$

where:

$A_w$  = Web area  
 $t_w$  = Web thickness

| For square panels with side length L, and shear force V:

$$A = L^2$$

$$\sigma_t = f_t / t_w = 2f_s / t_w$$

$$f_s = V / L$$

$$U = 2V^2 / E * t_w$$

The maximum displacement,  $\delta$ , is provided by:

$$\delta = \partial U / \partial V = 4 V / E * t_w$$

For the equivalent web,  $E = 10^7$  psi, and  $t_w = 0.019$  inches.

Assuming shear force on each of two webs equals half (1/2) the total weight, W, under a 10 g acceleration:

| 
$$V = 10 W / 2 = 5 W$$

The maximum axial stress in the frame members is:

$$\sigma_F = V * L / A_F * L = V / A_F$$

where, for the frame angles:

$A_F$  =  $1.5 * 1.5 * 0.19 = 0.4275 \text{ in}^2$   
 |  $\delta$  = Maximum shipping cage displacement  
 $\sigma_t$  = Web diagonal tension stress  
 $\sigma_F$  = Frame axial stress  
 MS = Margin of safety,  $F_y / \sigma - 1$ ,  $F_y = 20 \text{ ksi}$

| Calculated values for the shipping cage margins of safety are presented in [Table 2-23](#), by model.

**Table 2-23. Calculation of Shipping Cage Margins of Safety – All Models**

Model	V (lb.)	$\delta$ (in.)	L (in.)	$\sigma_t$ (ksi)	$\sigma_F$ (ksi)	MS
AOS-025	144	0.030	18.0	0.84	0.34	> 10
AOS-050	696	0.147	36.0	2.04	1.63	8.8
AOS-100	2,169	0.457	72.0	3.17	5.07	2.9

### 2.5.3.1.2 Analysis of Shipping Cage Fasteners – Model AOS-025

#### Vertical Frame

$$w = 0.1 \text{ lb/in}^3$$

$$W_1 = 4 * 18 * 1.5 * 1.5 * 0.19 * 0.1 = 3.1 \text{ lbs.}$$

$$H_1 = 9.0$$

#### Top Frame

$$W_2 = 4 * 18 * 1.5 * 1.5 * 0.19 * 0.1 = 3.1 \text{ lbs.}$$

$$H_2 = 18.0$$

#### Vertical Screens

$$w = 2.0 \text{ lb/ft}^2$$

$$W_3 = 4 * 1.5 * 1.5 * 2 = 18.0 \text{ lbs.}$$

#### Top Screen

$$w = 2.0 \text{ lb/ft}^2$$

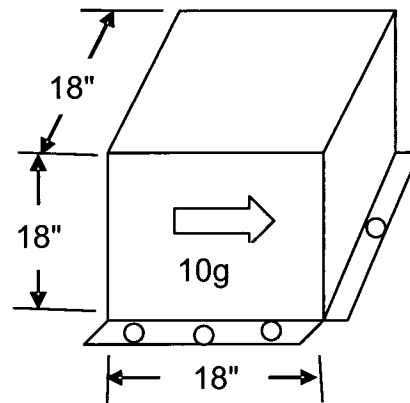
$$W_4 = 1.5 * 1.5 * 2 = 4.5 \text{ lbs.}$$

#### Fastener Properties

8-9/16 bolts

$$A_s = 0.1816$$

$$F_y = 20 \text{ ksi}$$



#### Maximum Inertia Force

$$G = 10.0g$$

#### Fastener Shear Stress

$$V = W_1 + W_2 + W_3 + W_4 = 3.1 + 3.1 + 18.0 + 4.5 = 28.7$$

$$\tau = (G * V) / (8 * A_s) = (10 * 28.7) / (8 * 0.1816) = 198 \text{ psi}$$

#### Fastener Axial Stress

$$M = (G (W_1 + W_3) * H_1) + (G (W_2 + W_4) * H_2)$$

$$= (10 (3.1 + 18.0) * 9.0) + (10 (3.1 + 4.5) * 18.0) = 3,258$$

$$L = 4.2$$

$$\sigma = M / (3 * L * A_s) = 3,258 / (3 * 4.2 * 0.1816) = 1,424$$

#### Equivalent Stress

$$f = \sqrt{(\sigma^2 + 3\tau^2)} = \sqrt{(1,424^2 + 198^2)} = 1,438 \text{ psi}$$

#### Margin of Safety

$$MS = F_y / f - 1 = 20,000 / 1,438 - 1 = 12.9$$

### 2.5.3.1.3 Analysis of Shipping Cage Fasteners – Model AOS-050

#### Vertical Frame

$$w = 0.1 \text{ lb/in}^3$$

$$W_1 = 4 * 32 * 1.5 * 1.5 * 0.19 * 0.1 = 28.8 \text{ lbs.}$$

$$H_1 = 16.0$$

#### Top Frame

$$W_2 = 4 * 36 * 1.5 * 1.5 * 0.19 * 0.1 = 32.4 \text{ lbs.}$$

$$H_2 = 32.0$$

#### Vertical Screens

$$w = 2.0 \text{ lb/ft}^2$$

$$W_3 = 4 * 2.5 * 3.0 * 2 = 60.0 \text{ lbs.}$$

#### Top Screen

$$w = 2.0 \text{ lb/ft}^2$$

$$W_4 = 3.0 * 3.0 * 2 = 18.0 \text{ lbs.}$$

#### Fastener Properties

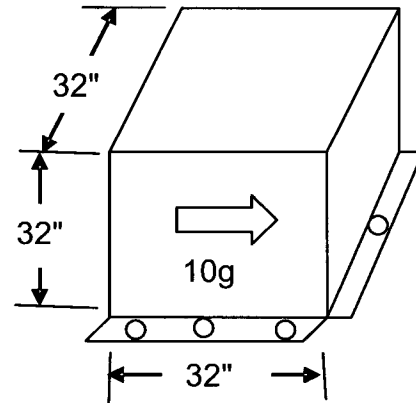
8-1/2 in. bolts

$$A = 0.137 \text{ in}^2$$

8-9/16 bolts

$$A_s = 0.1816$$

$$F_y = 20 \text{ ksi}$$



#### Maximum Inertia Force

$$G = 10.0g$$

#### Fastener Shear Stress

$$V = W_1 + W_2 + W_3 + W_4 = 28.8 + 32.4 + 60.0 + 18.0 = 139.2$$

$$\tau = (G * V) / (8 * A_s) = (10 * 139.2) / (8 * 0.137) = 1,270 \text{ psi}$$

#### Fastener Axial Stress

$$M = (G (W_1 + W_3) * H_1) + (G (W_2 + W_4) * H_2)$$

$$= (10 (28.8 + 60) * 16.0) + (10 (32.4 + 18) * 32.0) = 30,340$$

$$L = 30$$

$$\sigma = M / (3 * L * A_s) = 30,340 / (3 * 30.0 * 0.137) = 2,461 \text{ psi}$$

#### Equivalent Stress

$$f = \sqrt{(\sigma^2 + 3\tau^2)} = \sqrt{(1.27^2 + 3 * 2.46^2)} = 4.45 \text{ ksi}$$

#### Margin of Safety

$$MS = F_y / f - 1 = 20.0 / 4.45 - 1 = 3.49$$

### 2.5.3.1.4 Analysis of Shipping Cage Fasteners – Model AOS-100

#### Vertical Frame

$$w = 0.3 \text{ lb/in}^3$$

$$W_1 = 4 * 72 * 1.5 * 1.5 * 0.19 * 0.3 = 36.9 \text{ lbs.}$$

$$H_1 = 36.0$$

#### Top Frame

$$W_2 = 4 * 72 * 1.5 * 1.5 * 0.19 * 0.3 = 36.9 \text{ lbs.}$$

$$H_2 = 72.0$$

#### Vertical Screens

$$w = 2.0 \text{ lb/ft}^2$$

$$W_3 = 4 * 6.0 * 6.0 * 2 = 288.0 \text{ lbs.}$$

#### Top Screen

$$w = 2.0 \text{ lb/ft}^2$$

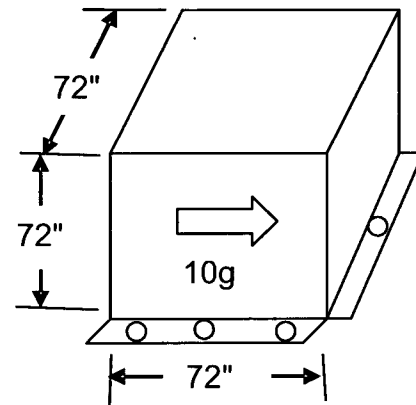
$$W_4 = 6.0 * 6.0 * 2 = 72.0 \text{ lbs.}$$

#### Fastener Properties

16-1/2 in. bolts

$$A = 0.137 \text{ in}^2$$

$$F_y = 20 \text{ ksi}$$



#### Maximum Inertia Force

$$G = 10.0g$$

#### Fastener Shear Stress

$$V = W_1 + W_2 + W_3 + W_4 = 36.9 + 36.9 + 288 + 72.0 = 433.8$$

$$\tau = (G * V) / (16 * A) = (10 * 433.8) / (16 * 0.137) = 1.97 \text{ ksi}$$

#### Fastener Axial Stress (assume 4 fasteners in tension)

$$M = (G (W_1 + W_3) * H_1) + (G (W_2 + W_4) * H_2)$$

$$= (10 (28.8 + 60) * 36.0) + (10 (32.4 + 18) * 72.0) = 57,917$$

$$L = 72$$

$$\sigma = M / (4 * L * A) = 57,917 / (4 * 72 * 0.137) = 1.47 \text{ ksi}$$

#### Equivalent Stress

$$f = \sqrt{(\sigma^2 + 3\tau^2)} = \sqrt{(1.97^2 + 3 * 1.47^2)} = 2.46 \text{ ksi}$$

#### Margin of Safety

$$MS = F_y / f - 1 = 20.0 / 2.46 - 1 = 7.13$$

### 2.5.3.2 Analysis of Impact Limiter Mechanical Connectors

Maximum stress in the impact limiter mechanical connectors occurs under a Side Drop. Configuration of forces in a Side Drop are illustrated in Figure 2-15, where  $P$  is the impact force due to a 30-ft. drop. The mechanical connectors are loaded by the moment produced by the couple forces,  $P/2$ , and the offset distance,  $d$ .

While the impact load,  $P$ , is known, the offset distance,  $d$ , is indeterminate and depends upon the stiffness of the cask and impact limiter. The connector force is evaluated by an FEA analysis that takes cask and impact limiter stiffness into account. A displacement pattern simulating deformation due to a Side Drop is applied to the impact limiter, and reacted by fixing the cask. The maximum stressed mechanical connector and attached rib are included in the model, and the force in the connector is determined by the analysis.

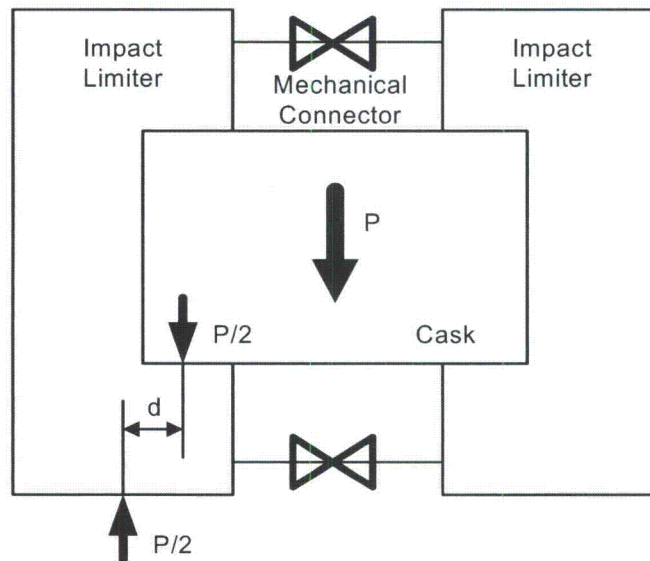


Figure 2-15. Side Drop Impact Forces



### 2.5.3.2.1 Description of FEA Models

The Model AOS-100 cask and impact limiter FEA model used in the analysis is illustrated in [Figure 2-16](#). The FEA model contains 18,026 nodes and 18,281 elements, comprising 54,276 degrees of freedom (DOF). The foam stiffness used in the analysis is approximately the average foam stiffness value determined in the 30-ft. drop analysis. The impact loading due to the 30-ft. Side drop is applied by applying displacements to the impact limiter and fixing the top of the cask. The location of the applied displacements and fixed nodes are illustrated in [Figure 2-17](#). A check of the total reaction forces at the cask's fixed nodes is made, to ensure that sufficient loading is applied. A single mechanical connector and rib are modeled in the position that produces maximum stress. The connector is modeled as a spring element, and the spring force is found from the stress post-processor. FEA models for the Model AOS-025 and AOS-050 transport packages are scaled from the Model AOS-100 transport package, by a factor of 0.25 and 0.50, respectively.

LIBRA input data that defines the Side drop deformation is generated by the Fortran program, GENERATOR. This program uses the FEA model nodal data to search out the displaced nodes, and generates boundary condition records for these nodes. GENERATOR includes a SCALE parameter that accounts for the scaled Model AOS-025 and AOS-050 FEA models.

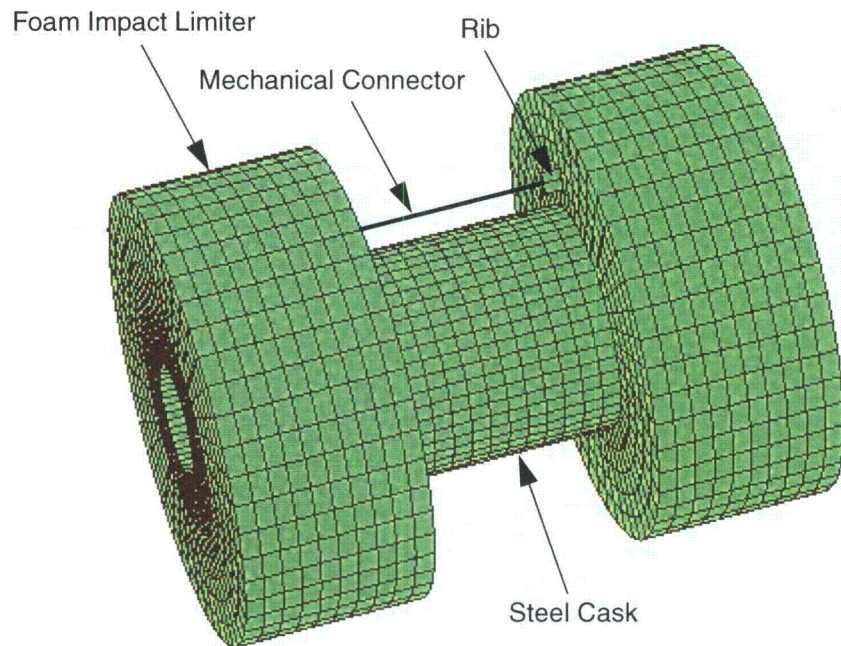


Figure 2-16. Cask and Impact Limiter FEA Model – Model AOS-100

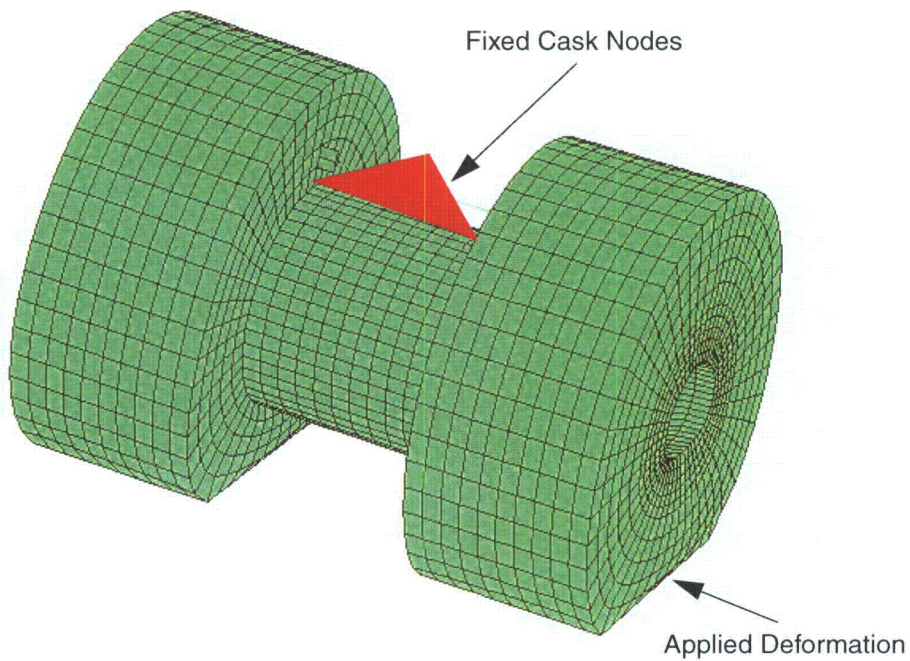


Figure 2-17. Cask and Impact Limiter Deformed FEA Model – Model AOS-100

### 2.5.3.2.2 Applied Force Check – Model AOS-025

The total force due to the applied displacements is the sum of y-direction (DOF\_2) reaction forces at the 11 fixed cask nodes. The fixed cask node numbers start at 1978 and increase sequentially by 150. The force summation is provided in Table 2-24.

In Load Case 305 of the SAR, the maximum side impact loading is  $1.80 \times 10^5$  lbs. Thus, the applied loading of  $1.861 \times 10^6$  lbs. is conservative.

**Table 2-24. Boundary Forces – Model AOS-025**

NODE	DOF_1	DOF_2	DOF_3
1978	-5.0006E-02	-2.4066E+04	-3.4473E-02
2128	2.4348E-03	-2.0315E+04	4.3499E-04
2278	-1.1101E-02	-1.6074E+04	-1.0881E-02
2428	4.7964E-03	-1.3833E+04	1.3197E-02
2578	-2.0154E-02	-1.2640E+04	-1.2181E-02
2728	-2.6443E-02	-1.2268E+04	8.6025E-03
2878	8.6144E-02	-1.2641E+04	-5.9291E-03
3028	4.3648E-02	-1.3837E+04	-2.1374E-02
3178	5.0801E-02	-1.6080E+04	2.2134E-02
3328	1.5450E-02	-2.0326E+04	-8.3435E-03
3478	5.2142E-03	-2.4082E+04	-2.0837E-02

$$\Sigma = -1.861 \times 10^5$$

### 2.5.3.2.3 Mechanical Connector Force – Model AOS-025

From the LIBRA stress post-processor, the force in the mechanical connector is:

$$F(025) = 306.4 \text{ lbs.}$$



#### 2.5.3.2.4 Applied Force Check – Model AOS-050

The total force due to the applied displacements is the sum of y-direction (DOF\_2) reaction forces at the 11 fixed cask nodes. The fixed cask node numbers start at 1978 and increase sequentially by 150. The force summation is provided in [Table 2-25](#).

In Load Case 305 of the SAR, the maximum side impact loading is  $3.30 \times 10^5$  lbs. Thus, the applied loading of  $3.74 \times 10^6$  lbs. is conservative.

**Table 2-25. Boundary Forces – Model AOS-050**

NODE	DOF_1	DOF_2	DOF_3
1978	-3.5198E-02	-4.8342E+04	-2.7608E-02
2128	1.5677E-02	-4.0804E+04	5.3950E-03
2278	7.9958E-03	-3.2282E+04	-5.5868E-03
2428	2.7825E-02	-2.7781E+04	8.8376E-03
2578	8.2703E-03	-2.5383E+04	3.4030E-04
2728	-4.5529E-02	-2.4638E+04	1.9109E-02
2878	9.0454E-02	-2.5389E+04	-1.3850E-02
3028	4.1124E-02	-2.7793E+04	-1.7814E-02
3178	1.9868E-02	-3.2303E+04	1.7507E-02
3328	-2.8472E-03	-4.0837E+04	-4.7354E-03
3478	-5.0954E-03	-4.8386E+04	-1.6034E-02

$$\Sigma = -3.738 \times 10^5$$

#### 2.5.3.2.5 Mechanical Connector Force – Model AOS-050

From the LIBRA stress post-processor, the force in the mechanical connector is:

$$F(050) = 598.5 \text{ lbs.}$$

### 2.5.3.2.6 Applied Force Check – Model AOS-100

The total force due to the applied displacements is the sum of y-direction (DOF\_2) reaction forces at the 11 fixed cask nodes. The fixed cask node numbers start at 1978 and increase sequentially by 150. The force summation is provided in [Table 2-26](#).

In Load Case 305 of the SAR, the maximum side impact loading is  $1.36 \times 10^6$  lbs. Thus, the applied loading of  $1.50 \times 10^6$  lbs. is conservative.

**Table 2-26. Boundary Forces – Model AOS-100**

NODE	DOF_1	DOF_2	DOF_3
1978	-3.7453E-02	-1.9344E+05	-2.8953E-02
2128	-2.6102E-02	-1.6327E+05	-9.0397E-03
2278	1.5500E-02	-1.2917E+05	-9.9378E-04
2428	1.8349E-02	-1.1116E+05	-1.8342E-02
2578	2.2709E-02	-1.0156E+05	1.6758E-02
2728	-5.7000E-02	-9.8571E+04	-3.3229E-02
2878	3.0340E-02	-1.0157E+05	-2.4999E-03
3028	6.9976E-03	-1.1118E+05	-3.9185E-02
3178	-2.1879E-02	-1.2922E+05	-3.7539E-02
3328	1.4692E-02	-1.6335E+05	-1.7748E-02
3478	4.3024E-02	-1.9354E+05	-1.2194E-02

$$\Sigma = -1.50 \times 10^6$$

### 2.5.3.2.7 Mechanical Connector Force – Model AOS-100

From the LIBRA stress post-processor, the force in the mechanical connector is:

$$F(100) = 2.37 \text{ k}$$



### 2.5.3.2.8 Side Impact Load Summary

Table 2-27 summarizes the mechanical connector side impact loads, by model.

Table 2-27. Mechanical Connector Impact Load Summary – All Models

Model	Impact Load (lbs.)	Applied Load (lbs.)	Total Connector Load (lbs.)	Quantity of Effective Connectors	Load/Connector (lbs.)
AOS-025	$1.80 \times 10^5$	$1.861 \times 10^5$	306.4	2	153
AOS-050	$3.30 \times 10^5$	$3.738 \times 10^5$	598.5	2	300
AOS-100	$1.36 \times 10^6$	$1.500 \times 10^6$	2,370.0	2	1,185

### 2.5.3.2.9 Mechanical Connector Stress Analysis

Two loading conditions are considered in the mechanical connector stress analyses:

- Connector impact loads due to side impact
- 10g impact limiter mass inertia load

Table 2-28 lists the 10g inertia loads, with connector load, P, provided by:

$$P = (10 * W) / 8$$

where:

W = Weight of a single impact limiter

Inertial force = 10g

Connectors = Eight (8) mechanical connectors

A comparison of Table 2-27 and Table 2-28 shows that the side impact loadings summarized in Table 2-27 produce maximum connector load, for all three (3) transport package models.

Table 2-28. Mechanical Connector Loads for 10g Inertia Force – All Models

Model	Limiter Weight (lbs.)	Connector Load (P) (lbs.)
AOS-025	14.0	17.5
AOS-050	62.0	77.5
AOS-100	515.0	643.8

### 2.5.3.2.9.1 Mechanical Connector Stress Analysis – Model AOS-025

In the Model AOS-050 transport package, the critical stress is the connection of the skin and J-bolt box. For the bearing, use  $F = 18.0$  ksi. (Refer to [Figure 2-18](#).)

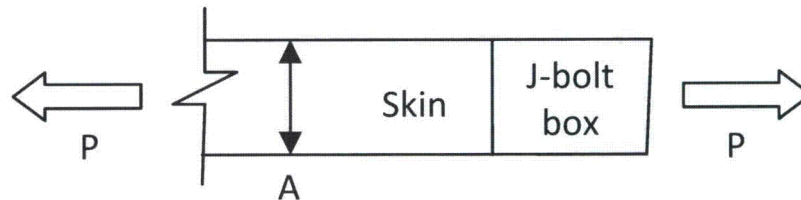


Figure 2-18. Critical Stress at Skin and J-Bolt Box Connection – Model AOS-025

where:

A	=	1.0 in.
t	=	0.05 in.
P	=	153 lbs.
$\sigma$	=	$P / A * t = 153 (1.0 * 0.05) = 3.06$ ksi
F	=	18.0 ksi
MS	=	$(18.0 / 3.06) - 1 = 4.9$

### 2.5.3.2.9.2 Mechanical Connector Stress Analysis – Model AOS-050

In the Model AOS-050 transport package, the critical stress is the bearing of a connector pin on a rib. For the bearing, use  $F = 40.0$  ksi. (Refer to [Figure 2-19](#).)

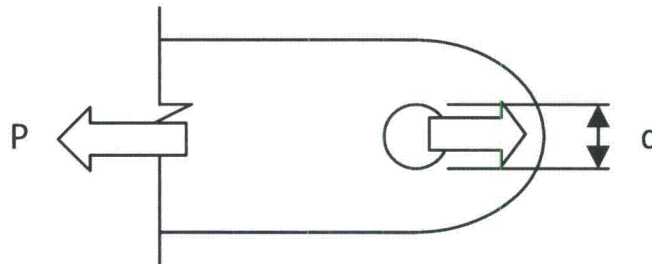


Figure 2-19. Critical Stress at Rib Connector Pin's Bearing – Models AOS-050 and AOS-100

where:

$$d = 0.125 \text{ in.}$$

$$t = 0.09 \text{ in.}$$

$$P = 300 \text{ lbs.}$$

$$A = d * t$$

$$\sigma = P / A = 300 / (0.125 * 0.09) = 26.7 \text{ ksi}$$

$$F = 40.0 \text{ ksi}$$

$$MS = (40.0 / 26.7) - 1 = 0.50$$

### 2.5.3.2.9.3 Mechanical Connector Stress Analysis – Model AOS-100

In the Model AOS-100 transport package, the critical stress is the bearing of a connector pin on a rib. For the bearing, use  $F = 40.0$  ksi. (Refer to [Figure 2-19](#).)

where:

$$d = 0.5 \text{ in.}$$

$$t = 0.125 \text{ in.}$$

$$P = 1,185 \text{ lbs.}$$

$$A = d * t$$

$$\sigma = P / A = 1,185 / (0.5 * 0.125) = 19.0 \text{ ksi}$$

$$F = 40.0 \text{ ksi}$$

$$MS = (40.0 / 19.0) - 1 = 1.10$$



### 2.5.3.3 Analyses of Shielding Devices

#### 2.5.3.3.1 Stress Analysis of Cavity Liner – Model AOS-025

The Model AOS-025's tungsten alloy cavity liner is analyzed for stress due to maximum accelerations under 9-m (30-ft.)-drop impact loadings.

**Note:** The acceleration values used for this analysis envelopes the maximum accelerations.

The following data is used in the analysis:

Longitudinal Acceleration	$A_z = 2,072 \text{ g}$
Lateral Acceleration	$A_y = 1,707 \text{ g}$
Elastic Modulus	$E = 45.0 \times 10^6 \text{ lb/in}^2$
Poisson's Ratio	$\nu = 0.3$
Yield Stress	$F_y = 94.0 \times 10^3 \text{ lb/in}^2$
Density	$\rho = 0.7 \text{ lb/in}^3$ (actual density is 0.655, rounded up to the more-conservative value, 0.7)

The cavity liner is analyzed using the LIBRA FEA program. The LIBRA model for this analysis is illustrated in [Figure 2-20](#). The model contains 35,966 nodes and 30,400 elements, comprising 107,871 degrees of freedom. A 180° liner segment, with symmetry boundary conditions, is analyzed. The liner is analyzed separately for a 2,072 g longitudinal (Z direction) inertia loading, and a 1,707 g lateral (Y direction) inertia loading. For longitudinal loading, the cross-section at one end of the liner is fixed against longitudinal motion. For transverse loading, a longitudinal line of nodes is fixed against lateral motion. A small hole at the liner ends is included, to facilitate modeling. The LIBRA pre-conditioned conjugate gradient (PCG) solver is used.

The cavity liner equivalent (Von Mises) stress due to the longitudinal inertia loading is illustrated in [Figure 2-21](#). The maximum equivalent stress for longitudinal loading is  $f_e = 8.83 \text{ ksi}$ . The minimum margin of safety is then:

$$MS = F_y / f_e - 1 = 94.0 / 8.83 - 1 = 9.6$$

The cavity liner equivalent stress due to transverse inertia loading is illustrated in [Figure 2-22](#). From [Figure 2-22](#), the liner maximum equivalent stress under transverse inertia load is  $f_e = 16.2 \text{ ksi}$ . The minimum margin of safety is then:

$$MS = F_y / f_e - 1 = 94.0 / 16.2 - 1 = 4.8$$



UEC 0  
 APPL 0.000E+00  
 SOURCE OFF  
 SCALE 0.95  
 BOUNDARIES  
 X -0.400  
 Y 0.400  
 Z 0.000  
 4.500

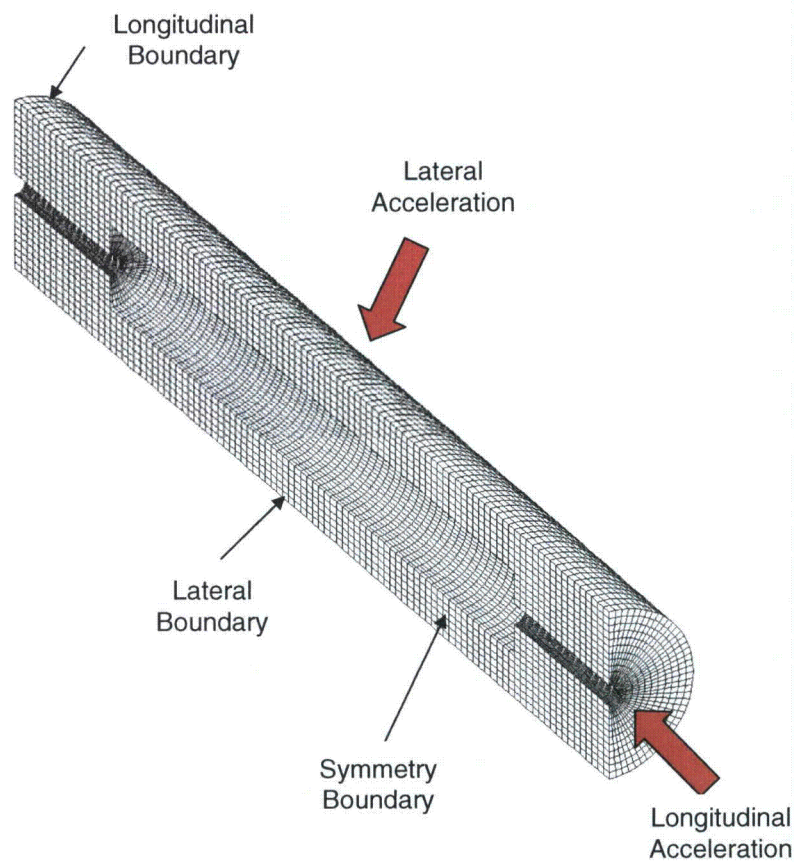


Figure 2-20. LIBRA Liner Model – Model AOS-025

ELEM TYPE: 10  
 COMPONENT: 7  
 VECTOR: 1

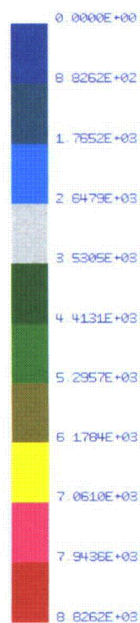


Figure 2-21. Equivalent Stress Due to Longitudinal Acceleration – Model AOS-025

ELEM TYPE: 10  
COMPONENT: 7  
VECTOR: 1

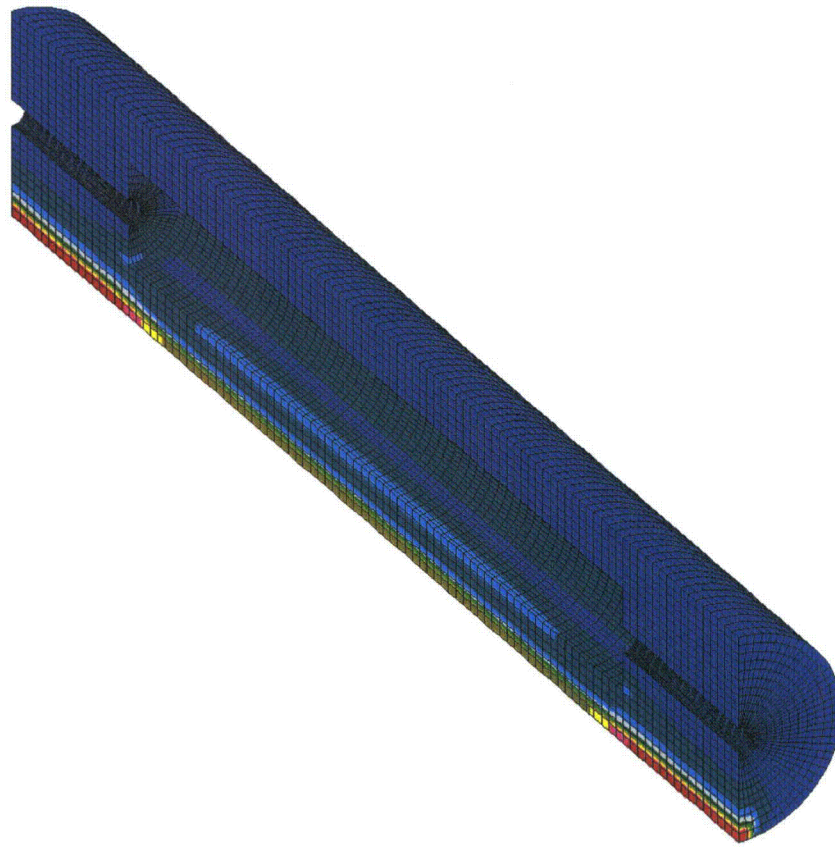
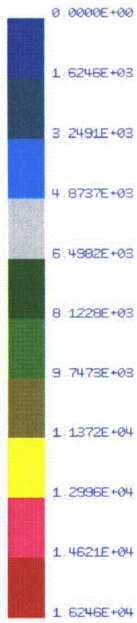


Figure 2-22. Equivalent Stress Due to Transverse Acceleration – Model AOS-025

### 2.5.3.3.2 Stress Analysis of Axial Shield Plate – Model AOS-100

The axial shield plate is a 15.24-cm (6-in.)-diameter, 3.81-cm (1.5-in.)-thick annular, tungsten alloy disk. For both Normal 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	$A_z = 250 \text{ g}$
Elastic Modulus	$E = 50.0 \times 10^6 \text{ lb/in}^2$
Poisson's Ratio	$\nu = 0.3$
Yield Stress	$F_y = 75.0 \times 10^3 \text{ lb/in}^2$
Density	$\rho = 0.655 \text{ lb/in}^3$

The axial shield 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 shield plate vertical (Y) displacements, and [Figure 2-24](#) illustrates axial shield 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  $1.91 \times 10^{-4}$  in. From [Figure 2-24](#), it can be seen that under the 250 g inertia load, the maximum equivalent stress is 13.9 ksi:

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



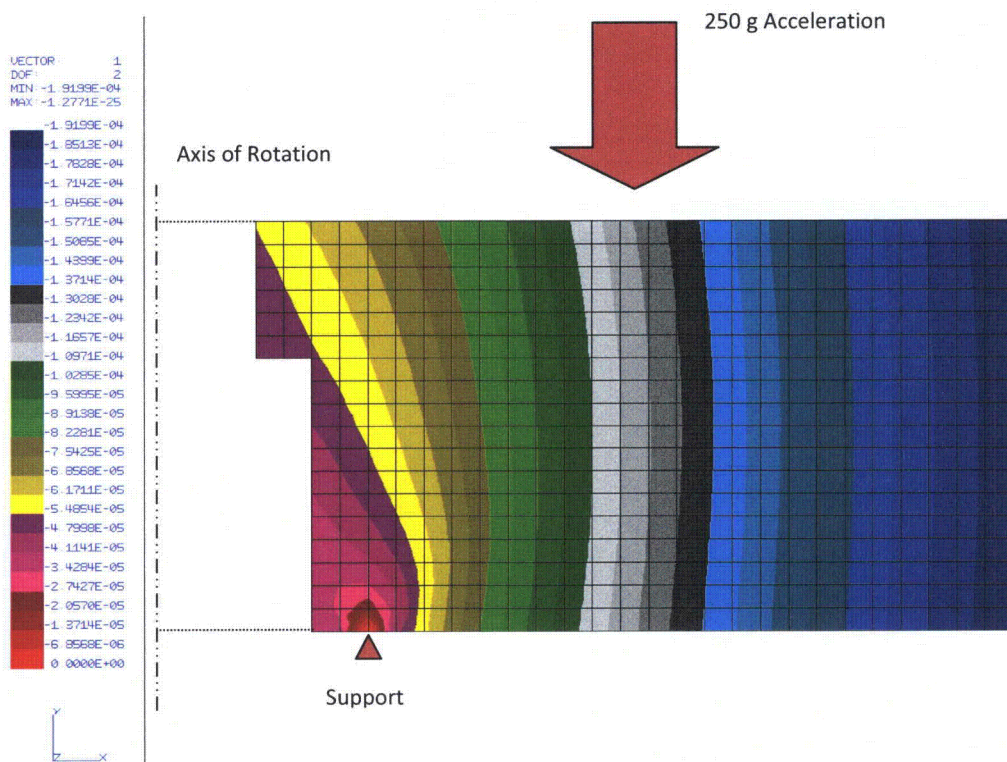


Figure 2-23. Axial Shield Plate Y-Displacements – Model AOS-100

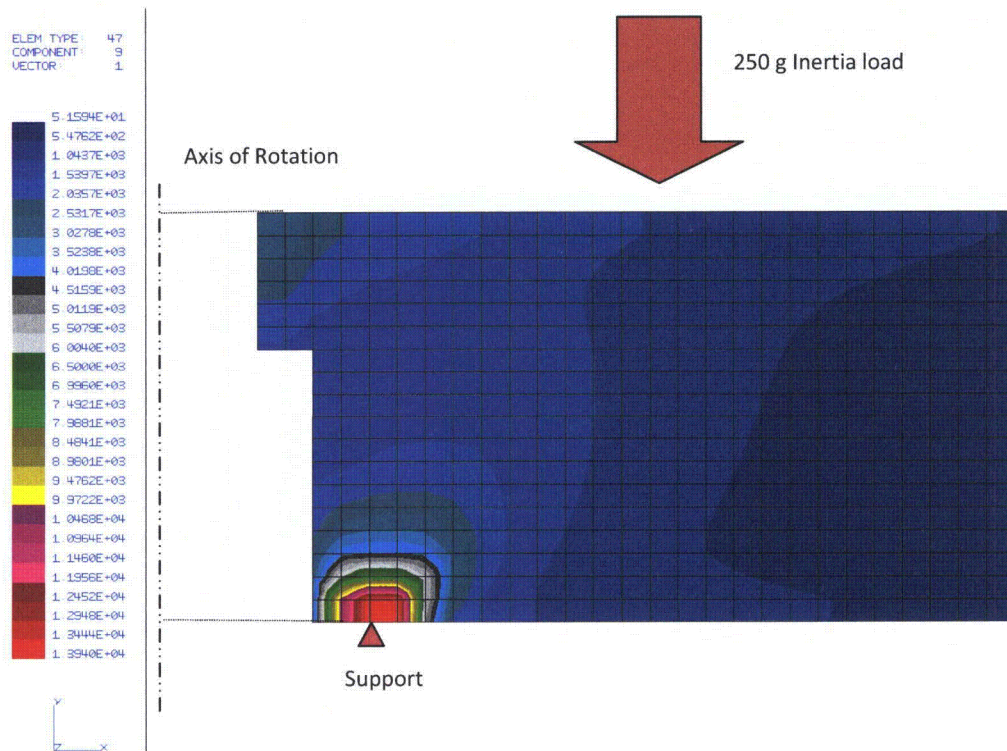


Figure 2-24. Axial Shield Plate Equivalent Stress – Model AOS-100



## 2.6 NORMAL CONDITIONS OF TRANSPORT

The AOS Transport Packaging System meets the requirements of Normal conditions of transport, as required in *10 CFR 71.71 [2.1]* and *IAEA Standard [2.2]*.

Normal conditions of transport are evaluated using the LIBRA Finite Element computer program. The LIBRA program conducts both linear and non-linear, static and dynamic, structural analyses. The LIBRA element library contains more than 60 elements, which include beam, shell, and standard and hierarchical 2D and 3D elements. The program contains 20 solution algorithms. The principal solution algorithms are static analysis, modal analysis, direct and modal dynamic response analysis, and heat transfer. As discussed in [Paragraph 2.1.2.4](#), three (3) Finite Element Analysis (FEA) analytical models are used in the evaluation.

| Refer to [Subsection 2.6.11](#) for a tabulation of the minimum Margin of Safety (MS) resulting from Normal conditions of transport.

### 2.6.1 Heat

| The thermal evaluation for the heat condition is presented in [Chapter 3, "Thermal Evaluation."](#) The heat condition consists of exposing the cask to direct sunlight and 38°C (100°F) still air. Insolation of the package is specified in *10 CFR 71.71(c)(1) [2.1]*. An initial temperature field of 21°C (70°F) and a maximum internal heat of the respective model are used for the evaluation. In addition, the decay heat of the content must be accounted for in some of the required analyses. The seven (7) thermal conditions (analyses) required to satisfy the regulations are tabulated in [Table 2-29](#).

The thermal loading temperature fields, Load Cases 101 through 106, 111, and 112, are taken directly from the heat transfer analyses, and applied to the stress models. The heat transfer and stress models are geometrically identical, with the same node numbering used in both analyses.

**Table 2-29. Transport Package Thermal Environment Conditions – All Models**

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

## 2.6.1.1 Summary of Pressures and Temperatures

Table 2-30 presents the maximum temperatures, throughout the transport package, resulting from Normal conditions of transport. The structural analyses are applied to the temperature field generated by the thermal analysis, to determine the thermal stresses.

Table 2-31 presents the pressure corresponding to the maximum temperature for each transport package model. This pressure value is based upon air at 100% relative humidity occupying the entire cavity volume. These pressures do not exceed the design pressure, which is also listed in Table 2-31. Therefore, the transport package can withstand pressures and temperatures in excess of those encountered in Normal conditions of transport.

Pressure-related Load Cases 201 through 204 are analyzed by the 2D cask model. Pressure is applied to the model's inside cask cavity wall or cask outside surface. The LIBRA LE -4<sup>a</sup> loading function is used to apply pressure loads. This function generates nodal forces in 2D models due to surface tractions along edge nodal lines. The nodal lines are defined by terminal nodes.

- 
- a. The LIBRA program's LE feature defines several types of edge and surface loadings. The first entry is a negative integer that distinguishes the type of loading. The types of loadings and nodal specifications are listed below, with former record types in parentheses.

### **Options Available when Applying the "LE" Command**

**Type -1** – General loading on nodes specified by numbering sequence.

**Type -2** – General loading on arc defined by control points (LE1).

**Type -3** – Surface pressure on arc defined by control points (LEP).

**Type -4** – Linearly varying pressure on line specified by end nodes.

**Type -5** – Linearly varying harmonic pressure on 3D model generated from a 2D model.

### **Further Details for Types -4 and -5**

**Type -4** – This command generates nodal loads corresponding to linearly varying surface tractions along a line on a 2D model. The line is specified by the two (2) terminal nodes, and loads are applied to all nodes within a specified distance of the line. The linearly varying pressure is specified by the terminal values.

**Type -5** – This command generates nodal loads corresponding to surface tractions over a 3D model generated from an axisymmetric (2D) model. The tractions may vary linearly along a radial line, and circumferentially as a Fourier harmonic. The loaded nodes are identified by specifying the two (2) terminal nodes on the zero meridian. The linearly varying pressure is specified by the corresponding terminal values on the zero meridian.



Table 2-30. Temperature Summary of Normal Conditions of Transport – All Models

Package Component	Maximum Temperatures, by Model							
	AOS-025A		AOS-050A		AOS-100A AOS-100A-S		AOS-100B	
	°C	°F	°C	°F	°C	°F	°C	°F
Cask Cavity	125	257	147	296	155	312	156	312
Shielding Material	124	256	142	288	148	298	148	298
Cask Seal Area	124	255	141	286	145	293	145	293
Cask Vent Port	124	255	140	284	143	290	143	290
Cask Drain Port	124	255	141	286	144	291	144	291
Test Port	124	255	141	286	145	293	145	293
Cask Vent Port Pipe Plug	124	255	140	285	143	290	143	290
Cask Drain Port Pipe Plug	124	255	141	286	144	292	144	292
Cask Vent Port Conical Seal	124	255	141	286	145	293	145	293
Cask Drain Port Conical Seal	124	255	142	288	147	296	147	297
Cask Outside Surface	124	256	142	287	146	295	146	295
Impact Limiter, Foam Materials	94	202	117	242	111	231	111	231
Accessible Outside Surface	48	119	45	113	41	106	41	106

Table 2-31. Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models

Model	Temperature		Pressure <sup>a</sup>			Design Pressure <sup>b</sup>	
	°C	°F	kPa	psia		kPa	psia
AOS-025A	125	257	135	20	<	207	30
AOS-050A	147	296	142	21	<	414	60
AOS-100A AOS-100A-S	155	312	145	21	<	1,930	280
AOS-100B	156	312	145	21	<	1,930	280

a. Pressure calculation is based upon the ideal gas law illustrated in Table 4-6, "Maximum Cask Cavity Pressure Due to Normal Conditions of Transport – All Models," footnote a.

b. Model AOS-100 transport package – Pressure value is based upon projected operating conditions.

### 2.6.1.2 Differential Thermal Expansion

The effects of thermal gradients on the AOS Transport Packaging System are included in the LIBRA Finite Element analyses. Therefore, these effects are also included in the Load Combination procedure, where maximum stress and stress margins are calculated. Refer to [Table 2-37](#) and [Table 2-56](#) for Normal and Hypothetical Accident conditions of transport, respectively.

### 2.6.1.3 Stress Calculations

This paragraph describes the effects of the following:

- [Thermal Stresses](#) (stresses induced within a structure when some or all of the parts are not free to expand nor contract in response to temperature changes)
- [Design Pressure Stresses](#) (stresses induced by pressure differentials)
- [Fabrication Stresses](#) (stresses resulting from welding operations)

#### 2.6.1.3.1 Thermal Stresses

The thermal loading temperature fields, Load Cases 101 through 106, 111, and 112, are taken directly from the heat transfer analyses, and applied to the stress models. The heat transfer and stress models are geometrically identical, with the same node numbering used in both analyses.

#### 2.6.1.3.2 Design Pressure Stresses

Pressure-related Load Cases 201 through 204 are analyzed by the 2D cask model. Pressure is applied to the model's inside cask cavity wall, or cask outside surface. The LIBRA LE -4<sup>a</sup> loading function is used to apply pressure loads. This function generates nodal forces in 2D models due to surface tractions along edge nodal lines, and the nodal lines are defined by terminal nodes.

#### 2.6.1.3.3 Fabrication Stresses

Fabrication stress loading is a displacement field modeling cask deformation due to welding. The displacement field produces bending at the weld cross-section, as illustrated in [Figure 2-25](#). A configuration of the weld is also shown for clarification. Dimensions provided in the weld sketch are those for the Model AOS-100. Equal and opposite displacements are applied to the inside surface of the cask cavity shell upper ring, and cask outer shell, and produce a prying load upon the dog-leg section of the inside shell. The dog-leg section is one of the most highly stressed locations within the cask. The magnitude of the applied displacement is based upon observed welding deformation. For the Model AOS-025, the applied displacement is 0.003175 mm (0.000125 in.). For the Model AOS-050 and AOS-100, the applied displacement is 0.0127 mm (0.0005 in.).

---

a. *Ibid* (refer to previous LIBRA LE -4 footnote a).

DEG 0  
 AMPL 0.000E+00  
 SHAPE OFF  
 SCALE 0.95  
 BOUNDRIES  
 X 0.000  
 Y 2.360  
 Z 6.424  
 8.601  
 0.000  
 0.000

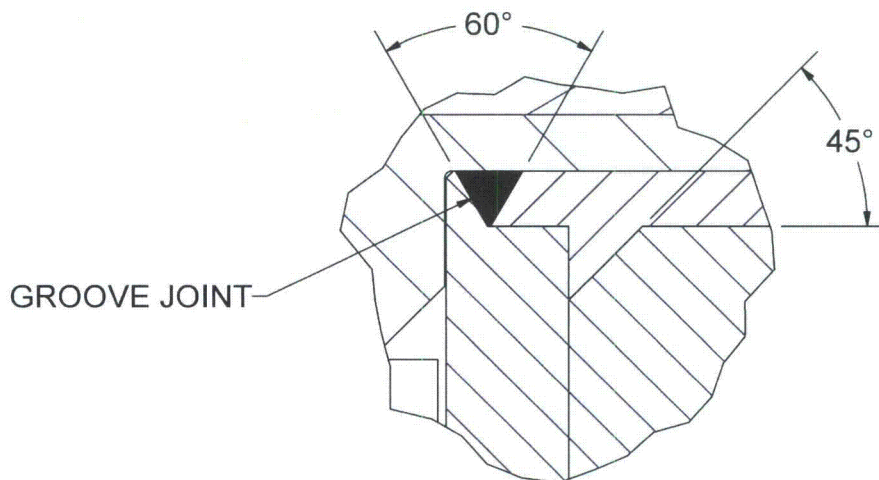
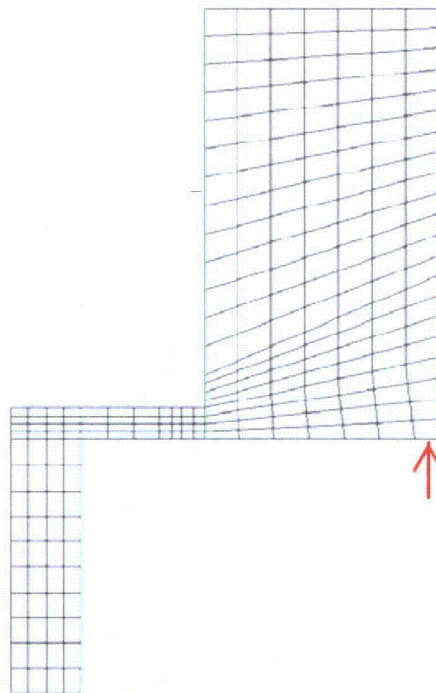


Figure 2-25. Typical Corner Cask Cavity Shell Weld Joint Configuration – All Models



### 2.6.1.4 Comparison with Allowable Stresses

Load Combinations 101 and 106 account for Heat Environment conditions of the Load Cases defined in Table 2-33. (The referenced tables for each model are located in Appendix 2.12.2, "Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100," within their respective paragraphs.)

**Table 2-32. Stresses Resulting from Load Combinations Associated with Heat Environment under Normal Conditions of Transport – All Models**

Load Combinations	Load Cases	Description	Data, by Model			
			AOS-025A	AOS-050A	AOS-100A AOS_100A-S	AOS-100B
101	102, 201, 211	Hot Environment	Table 2-84	Table 2-153	Table 2-222	Table 2-290
106	101, 201, 203, 211	Maximum Pressure, Hot Environment	Table 2-89	Table 2-158	Table 2-227	Table 2-295

### 2.6.2 Cold

The transport package must be able to withstand an ambient temperature of -40°C and -29°C (-40°F and -20°F, respectively), in still air and in the shade. Load Combinations 102, 105, and 107 account for Cold Environment conditions of the Load Cases defined in Table 2-33. (The referenced tables for each model are located in Appendix 2.12.2, "Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100," within their respective paragraphs.) For details regarding the specific conditions related to each of the listed Load Cases and Load Combinations, refer to Table 2-36 and Table 2-37, respectively.

Low-temperature service does not affect the AOS Transport Packaging System, because the majority of structural components are fabricated of SS300, a material that does not undergo ductile-to-brittle transition in the temperature range of interest, down to -40°C (-40°F). For the cask lid attachment bolt material – nickel alloy ASME SB-637, UNS N07718 – brittle failure is not a consideration per paragraph NB-2311(a)(7), in Reference [2.26], and the General Plastics FR-3700 series foam material has an operating temperature range down to -54°C (-65°F).

**Table 2-33. Stresses Resulting from Load Combinations Associated with Cold Environment under Normal Conditions of Transport – All Models**

Load Combinations	Load Cases	Description	Data, by Model			
			AOS-025A	AOS-050A	AOS-100A AOS_100A-S	AOS-100B
102	104, 201, 211	Cold Environment	Table 2-85	Table 2-154	Table 2-223	Table 2-291
105	105, 201, 202, 211	Cold Environment with Maximum Decay Heat	Table 2-88	Table 2-157	Table 2-226	Table 2-294
107	105, 201, 203, 211	Maximum Pressure, Cold Environment	Table 2-90	Table 2-159	Table 2-228	Table 2-296

### 2.6.3 Reduced External Pressure

Pressure-related Load Cases 201 through 204 are analyzed by the 2D cask model. Pressure is applied to the model's inside cask cavity wall or cask outside surface. The LIBRA LE -4<sup>a</sup> loading function is used to apply pressure loads. This function generates nodal forces in 2D models due to surface tractions along edge nodal lines. The nodal lines are defined by terminal nodes.

Load Cases 201 through 204 include the greatest pressure difference between the inside and outside of the transport package, as well as the inside and outside of the containment system, and are used to evaluate this condition in combination with the maximum normal operating pressure.

### 2.6.4 Increased External Pressure

The analysis for this condition is conducted in a similar manner as in [Subsection 2.6.3](#). Pressure-related Load Cases 201 through 204 are analyzed by the 2D cask model. Pressure is applied to the model's inside cask cavity wall or cask outside surface. The LIBRA LE -4 loading function is used to apply pressure loads. This function generates nodal forces in 2D models due to surface tractions along edge nodal lines. The nodal lines are defined by terminal nodes.

Load Cases 201 through 204 include the greatest pressure difference between the inside and outside of the package, as well as the inside and outside of the containment system, and are used to evaluate this condition in combination with the maximum design operating pressure.

### 2.6.5 Vibration

Vibration and shock loads are analyzed using the 3D model in three (3) separate analyses. The vibration and shock loads are, conservatively, assumed to be:

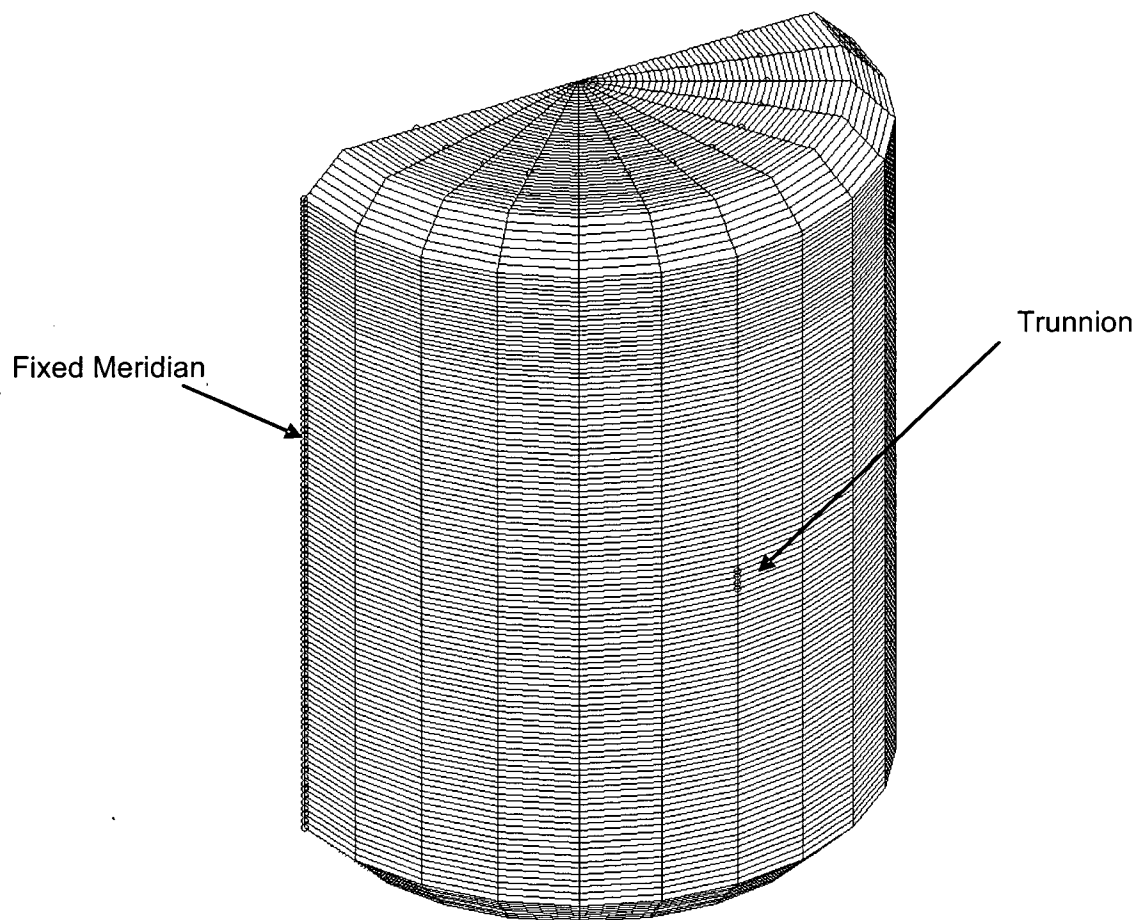
- **Load Case 221** – Forward 10g Vibration Inertia Load
- **Load Case 222** – Lateral 5g Vibration Inertia Load
- **Load Case 223** – Vertical 2g Vibration Inertia Load

In each analysis, displacements are fixed at the trunnions, and vertical displacement is fixed along the cask and truck bed contact line. The fixed nodes are illustrated in [Figure 2-26](#). The inertia loads are applied as body forces.

The analytical procedure applied to the cask lid attachment bolts of the AOS Transport Packaging System account for fatigue and vibration loads, in addition to preload, pressure, and temperature loads. Procedure setup provides infinite life service ( $1 \times 10^6$  cycles), based upon the ASME Code, Reference [\[2.14\]](#). (Refer to [Appendix 4.5.2](#), "Fortran Program Used to Analyze Cask Lid Attachment Bolts (Reference [4.6])," for details.)

---

a. *Ibid* (refer to previous LIBRA LE -4 footnote a).



**Figure 2-26. Fixed Points for Shock and Vibration Analyses**



## 2.6.6 Water Spray

The containment capabilities of the AOS Transport Packaging System are not compromised by water spray, because all external surfaces are comprised of stainless steel, and the closure seal is impervious to water. Furthermore, it is shown that the containment boundary of the AOS Transport Packaging System cask component is leak-tight, thus preventing water from entering the cask cavity. Refer to [Chapter 4, "Containment,"](#) for a description of the containment boundary and its capability to prevent leakage.

## 2.6.7 Free Drop

Each AOS Transport Packaging System model was analyzed to the effect of a free drop, using the LIBRA code. The transport package models were evaluated for a drop distance, based upon the model's weight, as listed in [Table 2-34](#). The Drop condition evaluation is based upon the energy displacement curves developed by the 30-ft. drop analysis. The maximum displacements are determined from the energy displacement curves, and are listed in [Table 2-35](#).

The analyses conducted consider three (3) orientations, as illustrated in [Figure 2-27](#). The orientation that produced the most stress upon the cask component of the AOS Transport Packaging System was used as the load condition to be included in the Load Combination procedure.

**Table 2-34. Free-Drop Distance – All Models**

Model	Maximum Authorized Package Weight <sup>a</sup>		Free-Drop Distance	
	kg	lbs.	m	ft.
AOS-025A	100	220	1.2	4
AOS-050A	681	1,500	1.2	4
AOS-100A	5,675	12,500	0.9	3
AOS-100B	4,994	11,000		
AOS-100A-S	5,675	12,500		

a. The weights that comprise the maximum authorized package weight are defined in [Table 2-7](#).

**Table 2-35. Maximum Displacements in Free Drops, Normal Conditions of Transport – All Models**

Model	Drop		Head-On		Side		Cg/Corner	
	cm	in.	cm	in.	cm	in.	cm	in.
AOS-025	121.9	48.0	1.52	0.60	0.96	0.38	2.54	1.00
AOS-050	121.9	48.0	3.81	1.50	3.05	1.20	6.73	2.65
AOS-100	91.4	36.0	6.60	2.60	5.08	2.00	12.19	4.80



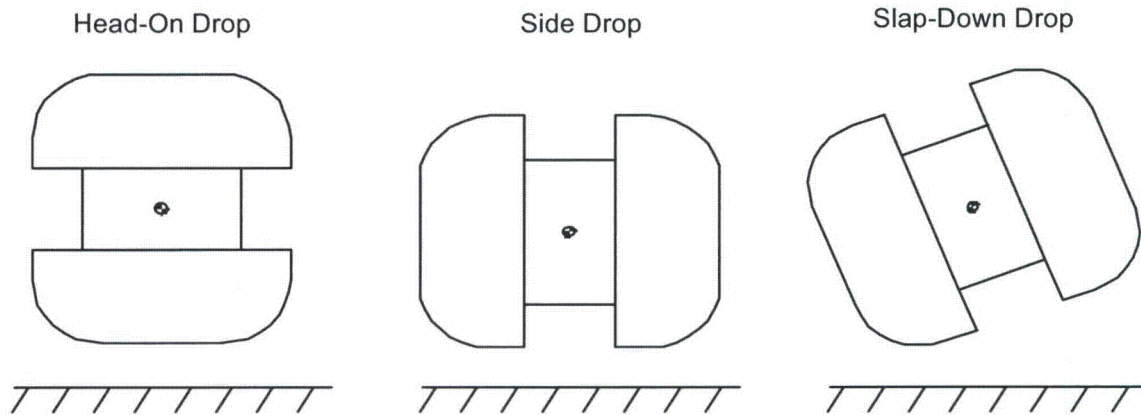


Figure 2-27. Head-On, Side, and Slap-Down Free-Drop Orientations

### 2.6.8 Corner Drop

Not applicable. This requirement applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 50 kg (110 lbs.) and fiberboard, wood, or fissile materials not exceeding 100 kg (220 lbs.).

### 2.6.9 Compression

The compression load of five times (5x) the cask weight is applied to the cask under Load Case 215. This analysis uses the 2D model. The compression force is applied to the top of the cask as a pressure loading, using the LE -4 load function.

### 2.6.10 Penetration

The regulations for Normal conditions of transport stipulate that the transport package must be capable of withstanding the impact of the hemispherical end of a vertical steel cylinder, that:

- Weighs 6 kg (13.23 lbs.)
- Has a 3.2-cm (1.26-in.) diameter
- Is dropped from a height of 1 m (40 in.), normally onto the exposed surface of the package that is expected to be the most vulnerable to puncture

The impact of a rod falling onto the cask, Load Case 216, was analyzed by a direct integration, dynamic analysis. The cask was modeled by the 2D model illustrated in Figure 2-28. The cask was assumed fixed at the base, and an impulse corresponding to the momentum impacting rod was applied at the top of the cask. Displacement at the impact point was monitored, as illustrated in Figure 2-29. The stress state at the time of maximum displacement was used for stress evaluation.

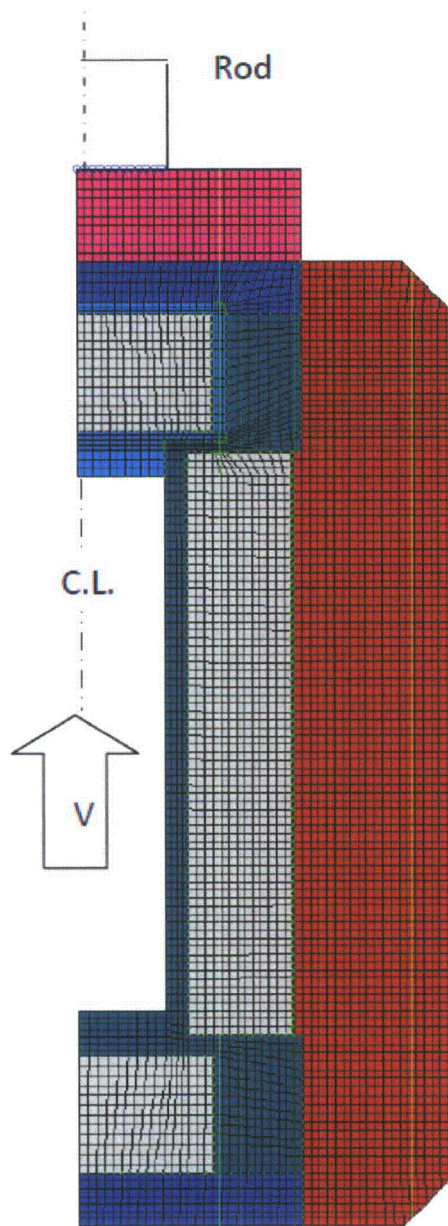
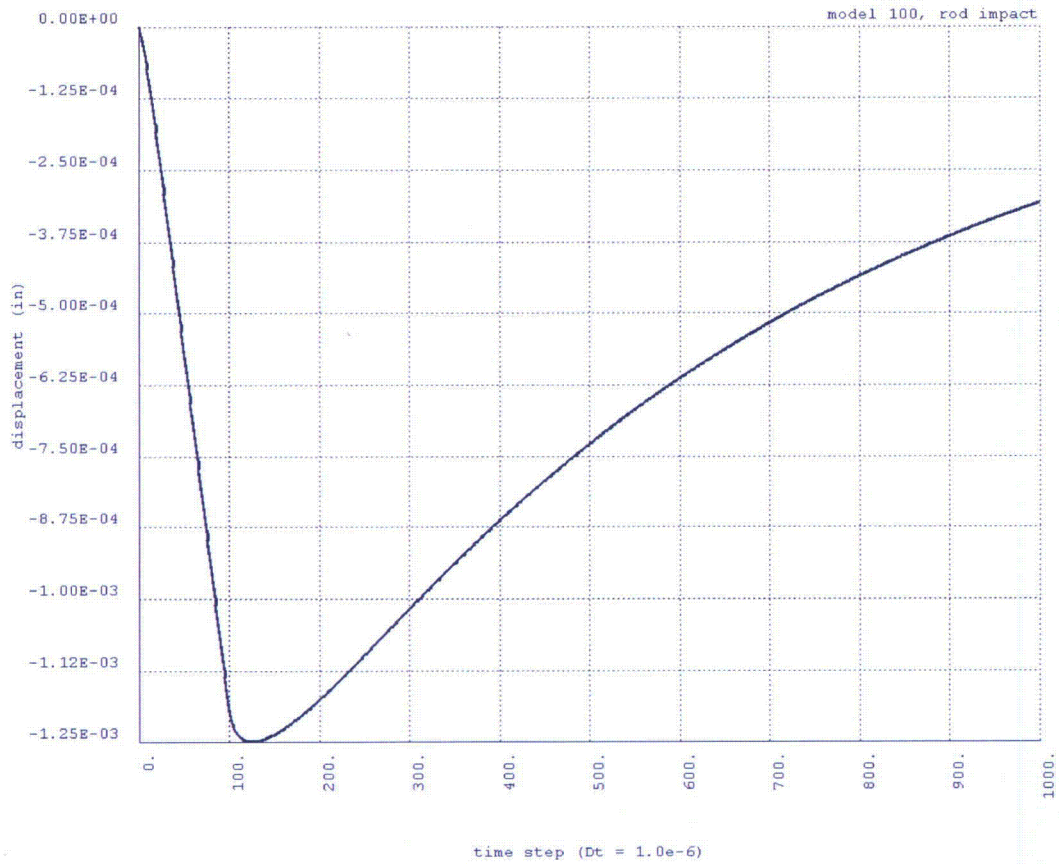


Figure 2-28. Rod Impact Analysis Load Distribution – Model AOS-100



**Figure 2-29. Rod Impact Time History Displacement at Impact Node – Model AOS-100**

### **2.6.11 Structural Evaluation Results Summary and Minimum Margins of Safety under Normal Conditions of Transport**

In this subsection, the resulting stresses from analyses for Normal conditions of transport are combined, following Reference [\[2.4\]](#) guidelines.

[Table 2-36](#) and [Table 2-37](#) identify the particular table in which the resulting stresses are reported for each AOS Transport Packaging System model, for all Normal conditions of transport Load Cases and Load Combinations, respectively. The referenced tables for each model are located in [Appendix 2.12.2, "Structural Evaluation Results – Models AOS-025, AOS-050, and AOS-100,"](#) within their respective paragraphs.

[Paragraph 2.6.11.1](#) provides the Minimum Margin of Safety (MS) obtained for each Load Combination and System model, under Normal conditions of transport.

This data shows that the AOS Transport Packaging System has the capacity to endure all Normal conditions of transport, without affecting its ability to contain and shield the radioactive material payload from undue risk to the public.



**Table 2-36. Load Cases under Normal Conditions of Transport  
Structural Evaluation Results – All Models**

Load Case	Description	Data, by Model			
		AOS-025A	AOS-050A	AOS-100A AOS-100A-S	AOS-100B
101	100°F Ambient, Maximum Decay Heat	Table 2-66	Table 2-135	Table 2-204	Table 2-272
102	100°F Ambient, Maximum Decay Heat, Maximum Insolation	Table 2-67	Table 2-136	Table 2-205	Table 2-273
103	-20°F Ambient, Zero Decay Heat, Zero Insolation	Table 2-68	Table 2-137	Table 2-206	Table 2-274
104	-40°F Ambient, Zero Decay Heat, Zero Insolation	Table 2-69	Table 2-138	Table 2-207	Table 2-275
105	-40°F Ambient, Maximum Decay Heat	Table 2-70	Table 2-139	Table 2-208	Table 2-276
106	-20°F Ambient, Maximum Decay Heat	Table 2-71	Table 2-140	Table 2-209	Table 2-277
201	Internal Design Pressure	Table 2-72	Table 2-141	Table 2-210	Table 2-278
202	Minimum External Pressure, 24 kPa (3.5 psia)	Table 2-73	Table 2-142	Table 2-211	Table 2-279
203	Maximum Increased External Pressure, 140 kPa (20 psia)	Table 2-74	Table 2-143	Table 2-212	Table 2-280
204	Additional Increased External Pressure, 2 MPa (290 psia)	Table 2-75	Table 2-144	Table 2-213	Table 2-281
211	Fabrication Stress	Table 2-76	Table 2-145	Table 2-214	Table 2-282
215	Compression Load (5x weight)	Table 2-77	Table 2-146	Table 2-215	Table 2-283
216	Rod Drop onto Cask	Table 2-78	Table 2-147	Table 2-216	Table 2-284
221	Forward 10g Vibration Inertia Load	Table 2-79	Table 2-148	Table 2-217	Table 2-285
222	Lateral 5g Vibration Inertia Load	Table 2-80	Table 2-149	Table 2-218	Table 2-286
223	Vertical 2g Vibration Inertia Load	Table 2-81	Table 2-150	Table 2-219	Table 2-287
231	3- or 4-ft. Head-On Drop	Table 2-82	Table 2-151	Table 2-220	Table 2-288
232	30-ft. Head-On Drop Impact Test, Normal Conditions	Table 2-83	Table 2-152	Table 2-221	Table 2-289

**Table 2-37. Load Combinations under Normal Conditions of Transport  
Structural Evaluation Results – All Models**

Load Combination	Load Cases	Description	Data, by Model			
			AOS-025A	AOS-050A	AOS-100A AOS-100A-S	AOS-100B
101	102, 201, 211	Hot Environment	Table 2-84	Table 2-153	Table 2-222	Table 2-290
102	104, 201, 211	Cold Environment	Table 2-85	Table 2-154	Table 2-223	Table 2-291
103	103, 202, 211	Increased External Pressure	Table 2-86	Table 2-155	Table 2-224	Table 2-292
104	101, 201, 202, 211	Minimum External Pressure	Table 2-87	Table 2-156	Table 2-225	Table 2-293
105	105, 201, 202, 211	Cold Environment with Maximum Decay Heat	Table 2-88	Table 2-157	Table 2-226	Table 2-294
106	101, 201, 203, 211	Maximum Pressure, Hot Environment	Table 2-89	Table 2-158	Table 2-227	Table 2-295
107	105, 201, 203, 211	Maximum Pressure, Cold Environment	Table 2-90	Table 2-159	Table 2-228	Table 2-296
215	215, 101, 201, 211	Compression Load	Table 2-91	Table 2-160	Table 2-229	Table 2-297
216	216, 101, 201, 211	Rod Drop	Table 2-92	Table 2-161	Table 2-230	Table 2-298
217	216, 104, 201, 211	Rod Drop, Cold Environment	Table 2-93	Table 2-162	Table 2-231	Table 2-299
221	221, 101, 201, 211	Forward Vibration	Table 2-94	Table 2-163	Table 2-232	Table 2-300
222	222, 101, 201, 211	Lateral Vibration	Table 2-95	Table 2-164	Table 2-233	Table 2-301
223	223, 101, 201, 211	Vertical Vibration	Table 2-96	Table 2-165	Table 2-234	Table 2-302
224	221, 103, 201, 211	Forward Vibration at Cold Temperature	Table 2-97	Table 2-166	Table 2-235	Table 2-303
225	222, 103, 201, 211	Lateral Vibration at Cold Temperature	Table 2-98	Table 2-167	Table 2-236	Table 2-304
226	223, 103, 201, 211	Vertical Vibration at Cold Temperature	Table 2-99	Table 2-168	Table 2-237	Table 2-305



**Table 2-37. Load Combinations under Normal Conditions of Transport  
Structural Evaluation Results – All Models (Continued)**

Load Combination	Load Cases	Description	Data, by Model			
			AOS-025A	AOS-050A	AOS-100A AOS-100A-S	AOS-100B
231	231, 102, 201, 211	3- or 4-ft. Head-On Drop, Normal Conditions	Table 2-100	Table 2-169	Table 2-238	Table 2-306
232 <sup>a</sup>	232, 102, 201, 211	30-ft. Head-On Drop, Normal Conditions (Impact Test)	Table 2-101	Table 2-170	–	–
233	231, 103, 211	3- or 4-ft. Drop at Cold Temperature	Table 2-102	Table 2-171	Table 2-239	Table 2-307

a. Load Combination 232 is documented only for the Model AOS-025A and AOS-050A transport packages, and demonstrates compliance with the requirements of IAEA TS-R-1, Paragraph 737 (Reference [2.2]).

## 2.6.11.1 Minimum Margins of Safety

Table 2-38 through Table 2-41 provide the Minimum Margin of Safety (MS) obtained for each Load Combination and Transport Packaging System model, under Normal conditions of transport.

**Table 2-38. Min MS for Normal Conditions of Transport – Model AOS-025A**

Ld_Cmb	Load_Cases						Min_MS	Loc	Str_Cmb
-----	-----						-----	---	-----
101	102	201	211	0	0		5.630E+00	20	Pm+Pb
102	104	201	211	0	0		2.146E+00	5	Pm+Pb+Q
103	103	202	211	0	0		2.841E+00	5	Pm+Pb+Q
104	101	201	202	211	0		2.943E+00	20	Pm+Pb
105	105	201	202	211	0		2.943E+00	20	Pm+Pb
106	101	201	203	211	0		2.889E+00	20	Pm+Pb
107	105	201	203	211	0		2.889E+00	20	Pm+Pb
215	215	101	201	211	0		5.457E+00	20	Pm+Pb
216	216	101	201	211	0		3.306E-01	15	Pm
217	216	104	201	211	0		3.306E-01	15	Pm
221	221	101	201	211	0		5.612E+00	20	Pm+Pb
222	222	101	201	211	0		5.567E+00	20	Pm+Pb
223	223	101	201	211	0		5.505E+00	20	Pm+Pb
224	221	103	201	211	0		2.717E+00	5	Pm+Pb+Q
225	222	103	201	211	0		2.704E+00	5	Pm+Pb+Q
226	223	103	201	211	0		2.686E+00	5	Pm+Pb+Q
231	231	102	201	211	0		2.821E+00	4	Pm+Pb
232	232	102	201	211	0		2.354E+00	4	Pm+Pb
233	231	103	211	0	0		2.678E+00	5	Pm+Pb+Q

**Table 2-39. Min MS for Normal Conditions of Transport – Model AOS-050A**

Ld_Cmb	Load_Cases						Min_MS	Loc	Str_Cmb
-----	-----						-----	---	-----
101	102	201	211	0	0		5.819E+00	4	Pm+Pb
102	104	201	211	0	0		2.164E+00	5	Pm+Pb+Q
103	103	202	211	0	0		2.771E+00	5	Pm+Pb+Q
104	101	201	202	211	0		5.535E+00	4	Pm+Pb
105	105	201	202	211	0		5.535E+00	4	Pm+Pb
106	101	201	203	211	0		4.918E+00	4	Pm+Pb
107	105	201	203	211	0		4.918E+00	4	Pm+Pb
215	215	101	201	211	0		4.990E+00	4	Pm+Pb
216	216	101	201	211	0		1.285E+00	15	Pm
217	216	104	201	211	0		1.285E+00	15	Pm
221	221	101	201	211	0		5.732E+00	4	Pm+Pb
222	222	101	201	211	0		5.775E+00	4	Pm+Pb
223	223	101	201	211	0		5.816E+00	4	Pm+Pb
224	221	103	201	211	0		2.681E+00	5	Pm+Pb+Q
225	222	103	201	211	0		2.684E+00	5	Pm+Pb+Q
226	223	103	201	211	0		2.686E+00	5	Pm+Pb+Q
231	231	102	201	211	0		3.266E+00	4	Pm+Pb
232	232	102	201	211	0		1.032E+00	4	Pm+Pb
233	231	103	211	0	0		2.454E+00	5	Pm+Pb+Q



**Table 2-40. Min MS for Normal Conditions of Transport – Model AOS-100A and AOS-100A-S**

Ld_Cmb	Load_Cases						Min_MS	Loc	Str_Cmb
-----	-----						-----	---	-----
101	102	201	211	0	0		1.196E+00	4	Pm+Pb
102	104	201	211	0	0		1.196E+00	4	Pm+Pb
103	103	202	211	0	0		5.387E+00	5	Pm+Pb+Q
104	101	201	202	211	0		1.146E+00	4	Pm+Pb
105	105	201	202	211	0		1.146E+00	4	Pm+Pb
106	101	201	203	211	0		1.087E+00	4	Pm+Pb
107	105	201	203	211	0		1.087E+00	4	Pm+Pb
215	215	101	201	211	0		9.375E-01	4	Pm+Pb
216	216	101	201	211	0		1.128E+00	15	Pm+Pb
217	216	104	201	211	0		1.128E+00	15	Pm+Pb
221	221	101	201	211	0		1.068E+00	4	Pm+Pb
222	222	101	201	211	0		1.176E+00	4	Pm+Pb
223	223	101	201	211	0		1.191E+00	4	Pm+Pb
224	221	103	201	211	0		1.068E+00	4	Pm+Pb
225	222	103	201	211	0		1.176E+00	4	Pm+Pb
226	223	103	201	211	0		1.191E+00	4	Pm+Pb
231	231	102	201	211	0		1.127E+00	4	Pm+Pb
233	231	103	211	0	0		5.347E+00	5	Pm+Pb+Q

**Table 2-41. Min MS for Normal Conditions of Transport – Model AOS-100B**

Ld_Cmb	Load_Cases						Min_MS	Loc	Str_Cmb
-----	-----						-----	---	-----
101	102	201	211	0	0		1.196E+00	4	Pm+Pb
102	104	201	211	0	0		1.196E+00	4	Pm+Pb
103	103	202	211	0	0		1.101E+01	4	Pm+Pb
104	101	201	202	211	0		1.146E+00	4	Pm+Pb
105	105	201	202	211	0		1.146E+00	4	Pm+Pb
106	101	201	203	211	0		1.087E+00	4	Pm+Pb
107	105	201	203	211	0		1.087E+00	4	Pm+Pb
215	215	101	201	211	0		9.375E-01	4	Pm+Pb
216	216	101	201	211	0		1.128E+00	15	Pm+Pb
217	216	104	201	211	0		1.128E+00	15	Pm+Pb
221	221	101	201	211	0		1.068E+00	4	Pm+Pb
222	222	101	201	211	0		1.176E+00	4	Pm+Pb
223	223	101	201	211	0		1.191E+00	4	Pm+Pb
224	221	103	201	211	0		1.068E+00	4	Pm+Pb
225	222	103	201	211	0		1.176E+00	4	Pm+Pb
226	223	103	201	211	0		1.191E+00	4	Pm+Pb
231	231	102	201	211	0		1.127E+00	4	Pm+Pb
233	231	103	211	0	0		1.043E+01	4	Pm+Pb

## 2.7 HYPOTHETICAL ACCIDENT CONDITIONS

The AOS Transport Packaging System, when subjected to the Hypothetical Accident conditions of transport specified in *10 CFR 71.73*, meets the performance requirements specified in *10 CFR 71 [2.1]*, Subpart E. This is demonstrated within this section where the Hypothetical Accident conditions of transport are addressed and shown to meet the applicable design criteria provided in [Subsection 2.1.2, "Design Criteria."](#)

The engineering evaluation for these regulatory conditions was conducted by using the LIBRA Finite Element program. The analytical model used was verified by a Free-Drop test of a 165% scaled-up version of the Model AOS-100A, referred to as "AOS-165A" and/or "prototype" in the discussions. The testing conducted and results are also briefly discussed within this section; however, the complete test report is included in [Appendix 2.12.6](#).

The scaled-up Free-Drop test was conducted at General Electric, Vallecitos Nuclear Center, Sunol, California, for Alpha-Omega Services, Inc., of Bellflower, California. In addition, Alpha-Omega Services contracted CSA Engineering, Inc., of Mountain View, California, to instrument and record the test results, and RANOR, Inc., of Westminister, Massachusetts, to fabricate the prototype packaging. GE Nuclear Energy also contracted RANOR, Inc. to perform pre- and post-dimensional inspections. A copy of the Dimensional Inspection report is included in [Appendix 2.12.7](#).

For Free Drop evaluation, three orientations were analyzed:

- Head-On Drop
- Side Drop, including Slap-Down
- Cg/Corner Drop

The first two drop orientations were correlated to the Free-Drop test data, for validation of the analytical model and procedure used. The correlation work is also included in this section.

### 2.7.1 Free Drop

The AOS Transport Packaging System is described in [Subsection 2.1.1, "Discussion."](#) As discussed in that subsection, the cask component is covered at both ends by the impact limiter. The impact limiter is designed to absorb the energy developed during the drop, mitigating the drop's effect on the cask. The analysis presented in this subsection consists of two (2) parts:

- To identify the load onto the cask, by conducting a pseudo-static collapse analysis of the impact limiter, and
- To impose this resulting load onto the cask in the stress analysis

Hypothetical Accident conditions of transport are provided in [Appendix 2.12.2](#).

The AOS Transport Packaging System has an axisymmetric geometry. The Head-On Drop is oriented with the cask lid facing down, to produce the maximum damage on the cask lid seal joint. For the Side Drop, the cask is oriented to produce maximum side loading. The Slap-Down Drop is oriented to produce the maximum slap-down loading. The Cg/Corner Drop is oriented such that impact occurs on a line through the cask center of gravity.

**Note:** *The Cg/Corner Drop loading condition was not one of the orientations tested. This condition does not produce as critical a load as the Slap-Down loading. Additionally, the design has a recessed cask lid, which protects the cask lid metallic seal and cask lid attachment bolts.*

The Impact (Free-Drop) test is conducted to obtain data to demonstrate the adequacy of analytical methods used for qualifying the transport packages, both at the size tested and scaled-down versions. The AOS-165A was selected for this test because it is the largest package, in terms of size and weight. These analytical methods are used to show that the impact limiters are capable of limiting impact loads on the payload to an acceptable level.

Appendix 2.12.6 presents the Free-Drop Test report, which includes a detailed description of the test procedure. Appendix 2.12.7 presents the Dimensional Inspection report of the impact limiter and cask components, taken throughout the Free-Drop test. Appendix 2.12.13 presents the Certificate of Conformance for the General Plastics LAST-A-FOAM FR-3720 foam used in the AOS-165A prototype.

A 9-m (30-ft.) Drop test is conducted on a 165% scaled-up version of the Model AOS-100A, the AOS-165A prototype. The test article weighs approximately 18,144 kg (40,000 lbs.). Three (3) free drops, each with the package at a different orientation, are conducted as part of the test:

- **End (Head-On orientation)** – Package axis is vertically oriented
- **Side (Side orientation)** – Package axis is horizontally oriented
- **Slap-Down** – Package axis is oriented at a pre-determined angle with the impact plane to cause maximum slap-down load

Figure 2-30 illustrates the three (3) free drop orientations and test setup. The test sequence listed above can be changed during the tests. High-speed cameras from two (2) orthogonal directions were used to document the orientation prior to each drop. (Refer to Figure 2-31 for camera positioning.)

Acceleration time history data is recorded during the test, using accelerometers located inside the cask and on the impact limiter. A total of 10 sensors are used. One triaxial accelerometer is mounted on the impact limiter, at a location determined by CSA Engineering, Inc. (the company contracted to conduct the test). Two (2) triaxial accelerometers are mounted inside the payload cavity, one on each end of the dummy mass. Each triaxial accelerometer senses in the radial, tangential, and axial directions. The tenth sensor is a uniaxial accelerometer sensing in the vertical direction for the drop.

The impact force distribution on the cask surface is estimated using a pressure-sensing film applied prior to each drop and removed immediately afterward. The film is used on the top and curved surfaces of the cask, enclosed by the impact limiters.

In addition, a series of dimensional inspections of the cask and impact limiter are conducted before and after each drop, to establish the drop's resulting deformation pattern.

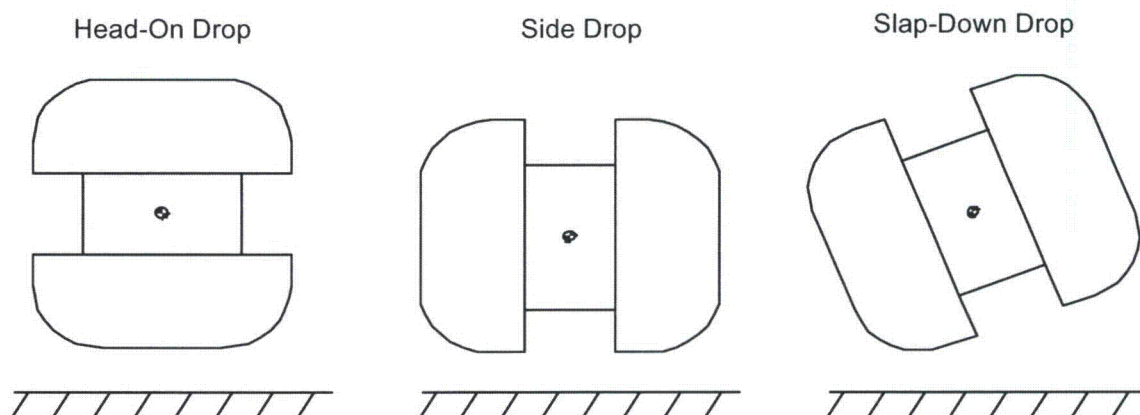


Figure 2-30. Head-On, Side, and Slap-Down Free-Drop Orientations



A portable 90-ton hydraulic crane is used to position the package at the proper height of 9m (30 ft.) or greater, above the impact surface. To prevent crane boom backlash after the load is released, the crane hook must be connected to two (2) dead weights by wire rope slings. This maintains the load on the crane after the package is released. (Refer to [Figure 2-31](#).)

A quick-release (air-actuated, pneumatic) mechanism is used to release the package and allow it to fall freely. The mechanism is attached to the crane hook and package holding gear [3.7-m (12-ft.) wire rope sling]. The only connections to the package during the drop are the light instrumentation cables. The cables are arranged so that they do not interfere with the free-fall path of the package. Attached to the slings is a 3-gallon air accumulator tank and fast-acting, electrically triggered diaphragm valve mounted close to the quick-release mechanism.

Drop height is determined by means of a light, graduated chain or measuring tape, hanging from the lowest point of the package to the ground. After the drop height is verified, the graduated chain or measuring tape is removed prior to the drop.

The primary pass-fail criterion for the test is based upon a Leak Rate test, conducted upon the transport package's cask component before and after the Drop tests. [Subsection 8.1.4, "Leakage Tests,"](#) details the Leak test methodology. An acceptable leak rate is less than  $2.96 \times 10^{-7}$  cm<sup>3</sup>/sec (helium), at a differential pressure of 1 atmosphere.

**Note:** *For the transport package to be judged acceptable, the measured leak rate must be less than this amount, both before and after the Drop tests.*

The secondary criterion relates to external transport package dimensions. These must not have changed by any amount that would prevent or endanger the transport package's performance of its primary functions – containment and shielding.





Figure 2-31. Test Setup (Head-On Orientation Shown) – AOS-165A Prototype