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2 STRUCTURAL EVALUATION

This section presents the structural design criteria, weights, mechanical properties of material, and structural evaluations which demonstrate that the Traveller series of packages meet all applicable structural criteria for transportation as defined in 10 CFR 71[1] and TS-R-1[2].

2.1 DESCRIPTION OF STRUCTURAL DESIGN

The structural evaluation of the standard length Traveller (Traveller STD) and the longer length Traveller (Traveller XL) packages are performed with various tests and computer simulation using finite element analysis. The results of the computer simulations and testing are provided in the following sections. Supporting analyses and analyses of not-tested structural aspects are also provided.

The Traveller shipping package consists of two major fabricated components: 1) an Outerpack assembly, and 2) a Clamshell assembly. The Outerpack consists of a stainless steel outer shell for structural strength, a layer of rigid polyurethane foam for thermal and impact protection, and a stainless steel inner shell for structural strength. Polyethylene blocks are affixed to the inner shell of the Outerpack for criticality safety. See Section 6, Criticality Evaluation, for full criticality safety description. The Clamshell consists of an aluminum container to structurally enclose the contents. Neutron absorber panels are affixed to the inner faces of the Clamshell. Rubber shock mounts separate and isolate the Clamshell from the Outerpack assembly. See Figure 2-1 for an exploded view of the Traveller STD package.

2.1.1 Discussion

The designs of the Traveller STD and Traveller XL unirradiated fuel shipping packages are the same except for length (and therefore weight). Details of the packages, including dimensions, and materials can be found in Section 1, General Information. Both packages consist of an Outerpack, and a Clamshell. Positive closure of the Outerpack is accomplished by means of high strength stainless steel bolts. The number of bolts is the same for the XL and STD designs, thus the loading per bolt is lower for the STD design. *There are 48 bolts ¾-inch bolts in the Outerpack, 24 attaching the hinge sections to the lower Outerpack and 24 attaching the upper Outerpack to the hinge sections. To remove the upper Outerpack, the 24 bolts must be removed. In the preferred approach, the Outerpack is opened when it is in a vertical orientation by removing the 12 bolts attaching the upper Outerpack to the hinges on one side. This allows the upper Outerpack to be opened on the other hinge sections, like a door. The design loadings for both packages are below the ultimate design loads for the Outerpack bolts. The worst case forces for the package are presented in Section 2.12.3.2.2, Horizontal Side Drops, and a discussion regarding the design allowable is presented in Section 2.12.3.7, Evaluation, Analysis and Detailed Calculations, and*

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Packaging and Transportation of Radioactive Material, January 1, 2004 Edition.

[2] TS-R-1 1996 Edition (Revised), Regulations for the Safe Transport of Radioactive Material.

Section 2.12.3.9, Bolt Factor of Safety Calculation. Further evidence of the adequacy of the Outerpack bolts is demonstrated through 9m drop testing whereby only one (1) Outerpack bolt failed in a total of nine (9) 9m drop tests. The single bolt that failed did so as a result of direct impact with the drop pad. The Clamshell is closed using ¼-turn nuts which lock latches on the doors of the assembly.

The Outerpack bolts and the Clamshell closure mechanisms have been subjected to the drop conditions of 10 CFR 71 and TS-R-1 without failure. Therefore, these designs are more than adequate to withstand the loads experienced during normal conditions of transport.

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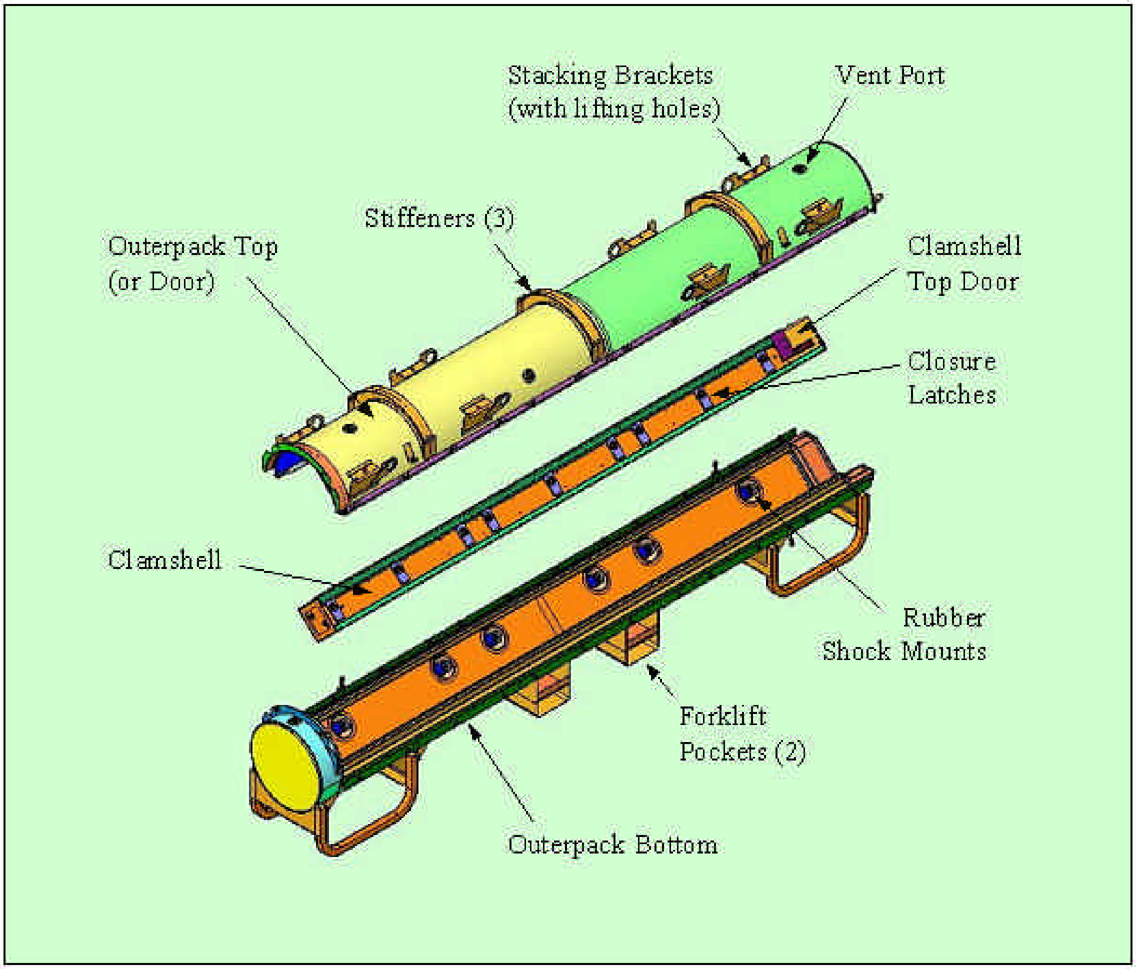

Figure 2-1 Traveller STD Exploded View

Closure of the Outerpack is provided by (12) ¾-10UNC hex head bolts, which allows the top half of the Outerpack assembly to swing open on a series of hinges. The Outerpack top half or "door" may be opened in either direction, depending on which bolts are removed. Optionally, the top Outerpack assembly may also be completely removed by removal of (24) ¾-10UNC hex head bolts. Closure of the Traveller STD and Traveller XL Clamshells are provided by latch assemblies that are secured with nine (9) ¼-turn nuts, and eleven (11) ¼- turn nuts, respectively.

The Traveller packages are not pressure sealed from the ambient environment, therefore, no differential pressures can occur within the package.

Handling of the packages is performed using the forklift pockets on the lower Outerpack. Handling may also utilize the lifting holes in the stacking brackets on the upper Outerpack.

Standard fabrication methods are utilized to fabricate the Traveller series of packages. Visual weld examinations are performed on all welds of the Traveller packages in accordance with AWS D1.6. and ASME Section III, Subsection NF-5360, for stainless steel and aluminum respectively.

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

Evidence of performance for the Traveller XL package is achieved by (1) empirical evaluations using full-scale packages and (2) large-strain capable Finite Element Analysis (FEA). The Traveller XL is bounding due to its increased weight and length when compared to Traveller STD. The criteria that was used for impact evaluation is a demonstration that the containment and confinement systems maintain integrity throughout Normal Conditions of Transport (NCT) and Hypothetical Accident Condition (HAC) certification testing. That is, it is necessary to demonstrate that there is no release of material, no loss of moderator or neutron absorber, no decrease in Outerpack geometry, and no increase in Clamshell geometry. The as-found condition of the package (packaging and contents) is the baseline configuration for the criticality safety evaluation that can be found in Chapter 6, Criticality Evaluation.

A detailed discussion related to Traveller XL design criteria, can be found in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package.

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The primary structural materials of the Traveller packages are austenitic stainless steel (ASTM A240 Type 304 SS) and 6000 Series aluminum (extruded components 6005-T5, all else 6061-T6). These materials do not undergo a ductile-to-brittle transition in the temperature range of interest [i.e., down to -40°F (-40°C)], and thus do not require evaluation for brittle fracture.

2.1.2.2.2 Fatigue

Because the shells of the Outerpack are constructed of ductile stainless steel and they are formed into a very stiff body with low resulting stresses, no structural failures of the Outerpack due to fatigue will occur. Because the Clamshell is structurally isolated from the Outerpack through the rubber shock mounts, no Clamshell fatigue will occur. The Clamshell is, for practical purposes, decoupled from the Outerpack through the rubber shock mounts. These rubber shock mounts also provide excellent damping to the Clamshell.

2.1.2.2.3 Buckling

For normal condition and hypothetical accident conditions, the Clamshell which structurally encloses the fuel, will not buckle due to free or puncture drops. This behavior has been demonstrated via full-scale testing of the bounding Traveller XL package.

2.1.3 Weights and Centers of Gravity

The Traveller XL weight bounds the Traveller STD weight as shown in Table 2-1. The calculated weight breakdown for the major individual subassemblies, including the shipping components for both packages, is listed below. For licensing purposes, the maximum bounding Traveller XL design weight is assumed to be 5,100 lb (2,313 kg).

Table 2-1 Summary of Traveller STD and Traveller XL Design Weights

	Traveller STD	Traveller XL
Outerpack Weight, lb (kg)	2368 (1074)	2633 (1194)
Max. Fuel Assembly Weight, lb (kg)	1650 (748)	1971 (894)
Clamshell Weight, lb (kg)	378 (171)	467 (212)
MAX. TOTAL WEIGHT, lb (kg)	4396 (1994)	5071 (2300)
DESIGN TARE WEIGHT, lb (kg)	2850 (1293)	3155 (1431)
DESIGN and LICENSING BASIS GROSS WEIGHT, lb (kg)	4500 (2041)	5100 (2313)

The center of gravity of both Traveller packages is approximately at the geometric center of the Outerpack, i.e., approximately 23 inches above ground level, at the axial mid-station for both packages. Appendix 2.12.1, Container Weights and Centers of Gravity, shows the overall dimensions and locations of the centers of gravity for both packages.

2.1.4 Identification of Codes and Standards for Package Design

The Traveller packages are evaluated with respect to the general standards for all packaging specified in 10 CFR §71.43, and TS-R-1 (paragraphs 606 – 649, as applicable). The fabrication, assembly, testing, maintenance, and operation will be accomplished with the use of generally accepted codes and standards such as ASME, ASTM, AWS. Special processes will be documented with procedures that will be evaluated and approved.

2.2 MATERIALS

2.2.1 Material Properties and Specifications

Mechanical properties for the materials used for the structural components of the Traveller packages are provided in this section. Temperature-dependent material properties for structural components are primarily obtained from Section II, Part D, of the ASME Boiler and Pressure Vessel (B&PV) Code. The analytic evaluation of the Traveller packages is via computer simulation (ANSYS/LS-DYNA®), only the material properties specific to the analysis portion and computer simulation portion of the evaluation are given. Table 2-2 lists the materials used in the Traveller packages and summarized key properties and specifications. More detailed material properties can be found in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package Traveller XL, and Appendix 2.12.3, Drop Analysis for the Traveller XL Shipping Package.

All materials used in the fabrication of the Certification Test Unit (CTU) meet 10 CFR 71 and TS-R-1 requirements. However, simulated neutron absorber plates were affixed to the inner faces of the Clamshell. These were fabricated from 1100-T0 aluminum ("dead soft" aluminum). These component plates did not contain boron, and were used to simulate the mechanical and thermal properties of borated aluminum material. The 1100-T0 aluminum was used due to its low mechanical properties. In production units, the actual borated aluminum plates will have insignificant differences in the material properties compared to the material used in the prototypes and CTU package.

2.2.2 Chemical, Galvanic, or Other Reactions

The Traveller series of packages are fabricated from ASTM A240 Type 304 stainless steel, 6000-series aluminum, borated 1100-series aluminum, polyurethane foam, and polyethylene sheeting. The stainless steel Outerpack does not have significant chemical or galvanic reactions with the interfacing components, air, or water.

The aluminum Clamshell is physically isolated, and environmentally protected, by the Outerpack and therefore will have negligible chemical or galvanic reactions with the interfacing components, air, or water. In addition, the Type 304 stainless steel fasteners which attach various Clamshell components represent a very small area ratio (cathode-to-anode ratio), which will render the reaction insignificant. Therefore, the requirements of 10 CFR §71.43(d), TS-R-1 (613) are met.

The Outerpack hinge bolts are zinc plated for the purpose of improving galling resistance which can be a significant problem when stainless steel fasteners are inserted in stainless steel threaded holes. The plating is not required for chemical or galvanic protection.

2.2.3 Effects of Radiation on Materials

There are no materials used in the Traveller packages which will be adversely affected by radiation under normal handling and transport conditions.

Table 2-2 Safety-Related Materials Used in the Traveller Packages

Material	Critical Properties	Reference Specifications/Codes	Comments
304 Stainless Steel	UTS: 75 ksi (517 MPa) YLD: 30 ksi (206 MPa) τ_{allow}: 18 ksi (124 MPa) E: 29.4 E6 psi (203 GPa)	ASTM A240 ASTM A276	Fully annealed material and not subject to brittle fracture.
6005-T6 Aluminum	UTS: 38 ksi (262 MPa) YLD: 35 ksi (241 MPa) τ_{allow}: 21 ksi (145 MPa) E: 10 E6 psi (69 GPa)	ASTM B221 ASTM B209	Reference standard UNS A96005
6061-T6 Aluminum	UTS: 45 ksi (310 MPa) YLD: 40 ksi (276 MPa) τ_{allow}: 24 ksi (165 MPa) E: 10 E6 psi (69 GPa)	ASTM B221 ASTM B209	Reference standard UNS A96061
Polyurethane Closed Cell Foam	Densities: 6 ± 1 pcf (0.096 ± 0.016 gm/cm^3), 10 ± 1 pcf (0.16 ± 0.016 gm/cm^3), 20 ± 2 pcf (0.32 ± 0.016 gm/cm^3) Crush Strengths: See Appendix 2.12.2	Westinghouse Specification PDSHIP02 ASTM D1621-94 ASTM D1622-93 ASTM D2842	Burn Characteristics verified by ASTM F-501, with exceptions noted in PDSHIP02.
UHMW Polyethylene	Specific Gravity: > 0.93 Molecular Wt: >3 million	ASTM D4020	N/A
Borated Aluminum Plate or Borated Aluminum Laminate Composite	Minimum areal densities: Borated Al Plate: 0.018 g/cm^2 Borated Al Composite: 0.024 g/cm^2	Westinghouse Specification PDSHIP04 ASTM C750 ASTM E748	The minimum areal densities are defined for the finished plate or laminate final thickness of 0.125" ± 0.006" (3.175 mm ± 0.153 mm). No structural credit is taken for the neutron poison plates.
Ceramic Insulation (Paper and Felt)	Max. use temp: >1800°F (982°C) Conductivity: ≤ 1.2 Btu-in/hr-ft^2 @ 500°F, (0.173 W/m-K @ 260°C)	N/A	The paper thickness is 0.0625" (1.59 mm), and the blanket thickness is 0.25" (6.35 mm)

2.3 FABRICATION AND EXAMINATION

2.3.1 Fabrication

The Traveller packages (XL and STD) are manufactured using standard fabrication techniques. No exotic materials or processes are required. Safety related items which are needed for criticality safety purposes have specific manufacturing specifications which clearly delineate all necessary codes, standards, and specifications required to meet design intent. All fabrication specifications are listed on the engineering drawings.

The fabrication processes of the Traveller include basic processes such as cutting, rolling, bending, machining, welding, and bolting. All welding is performed in accordance with ASME Section IX.

The manufacturing flow of the Traveller units includes fixturing of the inner and outer shells of the upper and lower Outerpack assemblies. Individual closure components are then aligned and welded in place. Sub-assemblies such as the forklift pockets, leg structures and stacking brackets are assembled in a parallel manner and appended to the main assemblies at appropriate times. Upon welding closure of the assemblies, the upper and lower Outerpack assemblies are secured together and poured with polyurethane foam material. Pouring of this material is tightly controlled through the foam manufacturing specification.

When the Traveller is filled with foam, it is ready for final assembly and installation of the Clamshell which has followed a parallel fabrication process. One difference for the Clamshell is that the faces are manufactured extrusions as opposed to "off-the-shelf" material. The extrusions are fabricated to industry standard specifications. Upon integration of the Clamshell to the Outerpack, final assembly and light grit blasting conclude the manufacturing process.

2.3.2 Examination

Manufacture of the Traveller XL and Traveller STD packages shall be performed in accordance with strict Quality Assurance (QA) requirements. Included in the manufacture of the packages are examinations to verify that each package is being built to the required specifications. These examinations include the following:

1. Receipt inspections whereby the received components are visually inspected for workmanship, overall part quality, dimensional compliance, and material certification compliance.

2. All welds (which shall be performed by qualified welders/processes) shall be visually examined by a qualified inspector in accordance with AWS D1.6 and ASME Section III, Subsection NF-5360, for stainless steel and aluminum respectively..

3. Examinations which evaluate form, fit, and function shall be performed on each package to verify its operability and assess its overall quality.

2.4 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

2.4.1 Lifting Devices

The lifting criteria is governed by 10 CFR §71.45(a) and TS-R-1 (607). 10 CFR §71.45(a) states that any lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in its intended manner. In addition, it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71. The following calculations are based on the features of the Traveller XL package which bounds the Traveller STD for these requirements. Lifting and tie-down are described in detail in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package.

2.5 GENERAL CONSIDERATIONS

The Traveller package structural evaluation consists of a combination of mechanical design calculations, finite element analysis, and testing. Table 2-3 shows the regulatory requirements and the means by which satisfactory compliance was demonstrated.

Table 2-3 Summary of Regulatory Requirements

Requirement Description	US NRC	TS-R-1	Applicable Condition	Means Demonstrated
Lifting attachments	10 CFR 71.45(a)	TS-R-1, § 607	General Package Standard	Mech. Design Calc.
Tie-Down devices	10 CFR 71.45(b)(1)	TS-R-1, § 636	General Package Standard	Mech. Design Calc.
Design temperatures between –40°F (-40°C) and 158°F (70°C)	10 CFR 71.71(c)(1,2)	TS-R-1, § 637 and 676	General Package Standard	Mech. Design Calc.
Internal/External Pressure	10 CFR 71.71(c)(3,4)	TS-R-1, § 615	Normal transport condition	Mech. Design Calc.
Vibration	10 CFR 71.71(c)(5)	TS-R-1, § 612	Normal transport condition	Mech. Design Calc.
Water spray	10 CFR 71.71(c)(6)	TS-R-1, § 721	Normal transport condition	Mech. Design Calc.
Compression/Stacking test	10 CFR 71.71(c)(9)	TS-R-1, § 723	Normal transport condition	Mech. Design Calc.
Penetration	10 CFR 71.71(c)(10)	TS-R-1, § 724	Normal transport condition	Mech. Design Calc.
Immersion	10 CFR 71.73(c)(6)	TS-R-1, § 729	Accident transport condition	Mech. Design Calc.

2.5.1 Evaluation by Test

The development of the Traveller packages included mechanical scoping tests to quantify the critical characteristics of the components or subsystems of the design. These scoping tests included:

1. Outerpack Hinge Strength-to-Failure Testing
2. Hinge Alignments Tests
3. Foam Pouring Tests
4. Foam Burn Tests (pail type)
5. Clamshell Hinge Strength-to-Failure Testing
6. Clamshell Weld Tests

7. Clamshell impact tests
8. Impact limiter testing including "pillow" impact testing

The scoping tests provided designers with performance data. However, proof of performance in the Traveller package was obtained through full-scale testing. As such, these tests were not required to be performed in accordance with full QA standard. However, all full-scale Traveller XL packages were fabricated and tested under all QA requirements.

The development of the Traveller consisted of essentially three (3) full-scale test campaigns. These campaigns consisted of what are called the Prototype units (2), the Qualification Test Units (QTU) (2), and finally the Certification Test Units (CTU) (1). In general, these packages are very similar. The overall configuration of the Outerpack and Clamshell remain essentially identical throughout the design evolution. With each test campaign, the design was modified to increase structural or thermal margin, or to reduce excess design margin when appropriate. The significant design changes from Prototype to CTU were:

1. The reduction in Outerpack shell thicknesses from 11 gage (0.120", 0.30 cm) to 12 gage (0.105", 0.27 cm),

2. The adjusting of polyurethane foam densities (first a lowering of density for structural reasons, then an increase for improve thermal performance),

3. The addition of a thin stainless steel covering of the moderator blocks,

4. The replacement of short individual Outerpack hinges with a continuous Outerpack hinge,

5. A redesign of the Clamshell head attachment configuration, and finally,

6. A reduction in the number and size of the Outerpack hinge bolts.

The purpose of the computer simulation was to assist in evaluating these minor changes and predict performance of the modified packages. The computer simulation was also used to show the impact of initial test conditions (temperature of package) and manufacturing variability (foam density tolerances, skin thickness variations, etc.). These factors showed negligible effects on the overall performance of the packages. Details can be found in Appendix 2.12.3, Drop Analysis for the Traveller XL Shipping Package.

A summary of the development and testing of the Traveller XL full-scale test packages is described in Table 2-5, and the detailed results of each test are described in Appendix 2.12.4, Traveller Drop Test Results.

2.5.2 Evaluation by Analysis

Analysis consisted of mechanical design calculations and finite element analysis. Mechanical design calculations are described in detail in Appendix 2.12.2. Finite element analysis, utilizing LS-DYNA software, is described in detail in Appendix 2.12.3.

Table 2-4 gives a summary of the regulatory requirements that are demonstrated through mechanical design calculations.

Table 2-4 Summary of Traveller Mechanical Analysis

Requirement Description	Allowable Design Value(s) or Acceptance Criteria	Calculated Value	Acceptable
Lifting attachments	Tensile Stress: $\sigma_{actual} < \sigma_y$ (30 ksi) Shear Stress: $\tau_{actual} < \tau_y$ (18 ksi) Weld shear Stress: $\tau_{actual} < \tau_{weld}$ (12 ksi) Hoist Screw Shear Stress: $\tau_{actual} < \tau_{allow}$ (60 ksi)	Hole tear: τ = 5.1 ksi< 18 ksi Weld: τ = 9.5 ksi< 12 ksi (Alt. 8.1 ksi< 12 ksi) Hoist: τ = 49.4 ksi< 60 ksi	Yes, for all
Tie-Down devices	Tensile Stress: $\sigma_{actual} < \sigma_y$ (30 ksi)	No tie down systems on package	Yes
Design temperatures between –40°F (-40°C) and 158°F (70°C)	No brittle fracture No impact from Differential Thermal Expansion (DTE)	No Impact	Yes
Internal/External Pressure	Tensile Stress: $\sigma_{actual} < \sigma_y$ (30 ksi)	No stress developed	Yes
Vibration	No impact on structural performance $f_{natOP} > f_{nat\ TRANS}$	No impact, 41 Hz > 3.7-8 Hz	Yes
Water spray	No impact on structural performance	No impact	Yes
Compression/Stacking test	Weld shear Stress: $\tau_{actual} < \tau_{weld}$ (12 ksi) Critical Buckling, $F < P_{cr}$	4.0 ksi < 12 ksi Outerpack; 25.5 ksi < 78.6 ksi Leg Support; 3.2 ksi < 26.9 ksi	Yes, for all
Penetration	No perforation of outer skin	Bounded by 1.0m HAC pin-puncture; No perforation of outer skin.	Yes
Immersion	Tensile Stress: $\sigma_{actual} < \sigma_y$ (30 ksi)	No stress developed	Yes

2.6 NORMAL CONDITIONS OF TRANSPORT

2.6.1 Heat

The thermal evaluation for the heat test is described and reported in Section 3, Thermal Evaluation.

2.6.1.1 Summary of Pressures and Temperatures

There is no pressure seal in the Traveller series of packages. Therefore, there is no pressure build up within the package. Maximum temperature for the following sections were evaluated to 158°F (70°C) and minimum temperatures to -40°F (-40°C).

2.6.1.2 Differential Thermal Expansion

The effects differential thermal expansion for the Traveller series of packages is negligible due to the design of the package. The most significant differential is between the aluminum Clamshell and the fuel assembly, and is less than 0.25 inches. The differential thermal expansion is accommodated by rubber-cork spacers between the Clamshell and fuel assembly.

Ultra-high Molecular Weight (UHMW) polyethylene does have a significantly higher coefficient of thermal expansion (CTE) when compared to Type 304 stainless steel. For this reason, the moderator panels are segmented along their lengths to accommodate the differential thermal expansion between the polyethylene and the inner stainless steel shells of the Outerpack. Additionally, oversized holes in the polyethylene panel are used to accommodate the effects of both temperature extremes.

See Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package, for detailed differential thermal expansion calculations.

2.6.1.3 Stress Calculations

The Traveller packages are fabricated from relatively thin sheet metal parts which are not subject to thermal gradients generated from the interior of the package. The packages are also not sealed to the environment, therefore pressure stress is negated. The most significant stress potential occurs from the differential expansion rates of the bolted polyethylene moderator panels to the inner steel shells of the Outerpack. This potential stress is also negated by design, whereby the panels are made in sections and the bolt clearances and gaps between panels are adequately sized to allow unrestrained growth and contraction.

Successful testing of full scale Traveller XL packages indicates that the stresses associated with differential thermal expansion of the various packaging components are negligible.

2.6.1.4 Comparison with Allowable Stresses

As discussed in Section 2.6.1.3, Stress Calculations, further evaluation of stresses associated with differential thermal expansion for the various Traveller package components is not required.

2.6.2 Cold

The materials used in construction of the Traveller packages are not degraded by cold at -40°C (-40°F). Stainless steel and aluminum exhibit no brittle fracture at these temperatures. Therefore, the requirements of 10 CFR §71.71(c)(2) and TS-R-1 (618) are satisfied.

2.6.3 Reduced External Pressure

Since the Traveller series of packages are not sealed against pressure, there can not be any significant differential pressure. However, calculations presented in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package, demonstrates that the package could withstand the differential pressure described in 10 CFR §71.71(c)(3) if the containers were sealed.

2.6.4 Increased External Pressure

Since the Traveller series of packages are not sealed against pressure, there can not be any significant differential pressure. However, information presented in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package, demonstrates that the package could withstand the differential pressure described in 10 CFR §71.71(c)(4) if the packages were sealed.

2.6.5 Vibration

The package must be evaluated to consider the effects of normal vibration on the design performance. The isolation system is designed to dampen normally induced vibrations from transport, and is not fundamental to the safe operation of the package. However, the Outerpack must maintain its structural integrity during transport to maintain a safe transport condition as specified in 10 CFR §71.71(5), TS-R-1 (612). Typical attachment to a transport conveyance for the Traveller packages includes nylon straps or chain mounted both over the package and on the gusset tray connected to the support legs pointed inboard. The loading configuration can be modeled as a simply supported beam. Furthermore, the Outerpack is conservatively modeled considering only the outer shell at the first mode of vibration. The typical natural frequency range for transportation vehicles, $f_{nat\ TRANS}$, is 3.7-8 Hz. The natural frequency of the Outerpack can be determined from:

$$f_{natOP} = a\sqrt{(EIg/l^3)/m}$$

where a=1.57 (primary mode coefficient assuming hinge-hinge end conditions for additional conservatism), E=29.4E6 psi, I=634 in^4, m=2633 pounds, g = 386.4 in/s^2 and l=158 in (distance from gusset tray to gusset tray). Substituting values:

$$f_{natOP} = 1.57\sqrt{[(29.4E6)(634)(386.4)/(158)^3]/2633} \text{ 1/s (Hz)}$$

$$f_{natOP} = 1.57\sqrt{693} \text{ Hz}$$

$$f_{natOP} = 41 \text{ Hz}$$

Since the natural frequency of the Outerpack is greater than the natural frequency typical of a transportation vehicle, resonance of the Outerpack is not expected and normally induced vibrations will not preclude the package from performing its design function.

The rubber shock mounts effectively isolate and dampen loads and vibrations to the Clamshell and its contents. No resonant vibration conditions which could fatigue the Clamshell shall occur during normal conditions of transport.

There are several natural frequencies of the shock mount system depending on direction of movement. The dominant frequency is for vertical movement. This frequency is between 5.9 and 6.7 Hz (for Traveller XL) depending on the weight of the fuel assembly being transported. The fore and aft pitch frequency is slightly higher (6.9-7.9 Hz) but has a lower amplitude. Road tests have been performed with the suspension system to measure amplitudes during shipping. Figure 2-1A is characteristic of the results seen. When the truck travels over a bump, the clamshell initially sees relatively large accelerations (2-3 g's) but this oscillation quickly damps out to accelerations less than 1 g. This 300 mi trip involved approximately five and a half hours on the road with 1.4 x 10^5 total cycles.

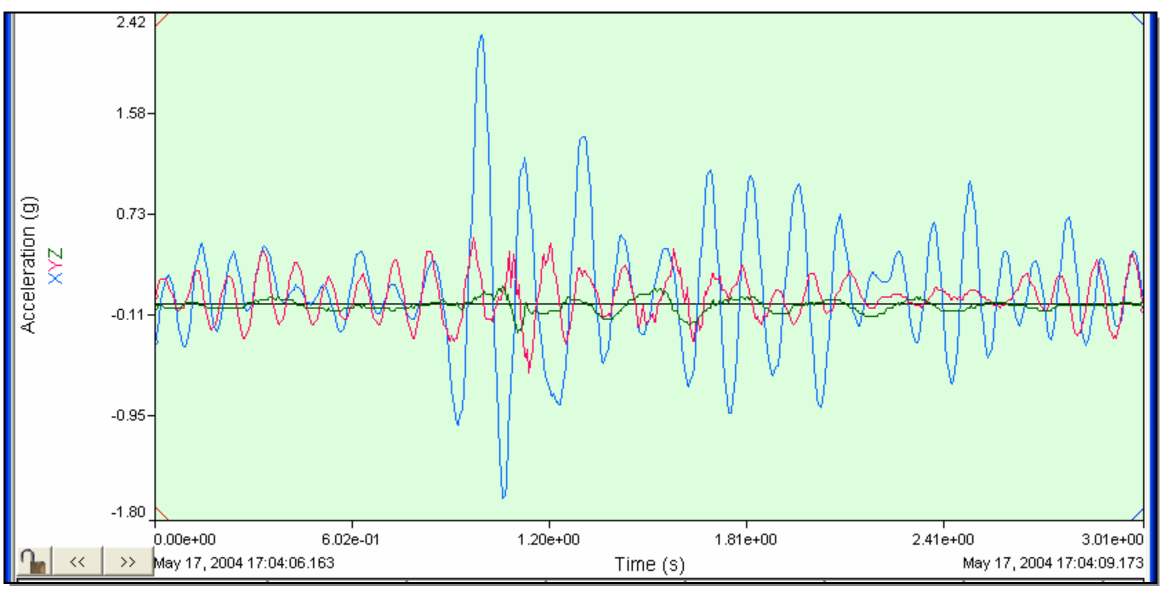

Figure 2-1A Sample of Clamshell Accelerations Measured During Road Test (May 11, 2004)

2.6.6 Water Spray

The materials of construction utilized for the Traveller packages are such that the water spray test identified in 10 CFR §71.71(c)(6), TS-R-1 (721), will have negligible effect on the package. Further, the Traveller Outerpack is cylindrical, and is specifically shaped to negate water collection. Since the Outerpack shell is fabricated from ASTM A240 Type 304 SS, the water spray will not impact the structural integrity of the package.

2.6.7 Free Drop

Since the gross weight of the bounding Traveller XL package is approximately 5,000 kg (11,000 lb), a 1.2 m (4 feet) free drop is conservatively required per 10 CFR §71.71(c)(7), TS-R-1 (722). As discussed in Appendix 2.12.4, Traveller Drop Test Results, 1.2 m drops were performed on the Traveller CTU as an initial condition for subsequent Hypothetical Accident Condition (HAC) tests.

The Traveller packages are well protected during drop testing. In particular, the leg structure including fork lift structure, stacking structure, and upper Outerpack stiffener I-beam structure, all protect the Traveller during impact. Traveller CTU free drop testing and analytical and engineering evaluations indicated that this testing have negligible impact on the integrity of the package. However, the orientation selected for the free drop testing was a low angle slap-down, approximately 10 degrees, with the package inverted. The basis for selection of this orientation was that this orientation offered the greatest opportunity to stress the welded joints at the ends of the package. Detailed descriptions of the test results are given in Appendix 2.12.4, Traveller Drop Test Results. Examinations following the prototypic and CTU testing proved the ability of the Traveller packaging to maintain its structural and criticality control integrity. Therefore, the requirements of 10 CFR §71.71(c)(7) are satisfied.

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2.6.8 Corner Drop

The corner drop test does not apply, since the gross weight of the package exceeds 100 pounds (50 kg), as specified in 10 CFR §71.71(c)(8) or 100 kg (221 lb) as specified in TS-R-1 (722).

2.6.9 Compression – Stacking Test

The compressive load requirement of 10 CFR §71.71(c)(9), TS-R-1 (723) is satisfied by the Traveller packages. Details of the analysis can be found in Appendix 2.12.2, Mechanical Design Calculations for the Traveller XL Shipping Package.

2.6.10 Penetration

The 1 m (40 inch) drop of a 1 ¼-inch (3.2 cm) diameter, 6 kg (13 pound), hemispherical end steel rod, as specified in 10 CFR §71.71(c)(10), TS-R-1 (724), is of negligible consequence to the Traveller series of packages. This conclusion is due to the fact that the Traveller packages are designed to minimize the consequences associated with the much more limiting case of a 1 m (40 inch) drop of the entire package onto a puncture rod, as discussed I Section 2.7.3, Puncture. The 12-gauge (2.7 mm) minimum thickness of the outer shell of the Outerpack is not damaged by the penetration event. Therefore, the requirements of 10 CFR §71.71(c)(10), TS-R-1 (724), are satisfied.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

When subjected to the hypothetical accident conditions as specified in 10 CFR §71.73, the Traveller package meets the performance requirements specified in Subpart E of 10 CFR 71, and TS-R-1 (726-737 as applicable). This conclusion is demonstrated in the following subsections, where the most severe accident condition is addressed and the package is shown to meet the applicable design criteria. The method of demonstration is through both computer analysis and by testing. The loads specified in 10 CFR §71.73 are applied sequentially, per Regulatory Guides 7.8 and 7.9 (draft).

The Traveller XL Certification Test Unit (CTU) test results are summarized in Section 2.7.7, Summary of Damage, with details provided in Appendix 2.12.4, Traveller Drop Test Results. Additional full-scale test results conducted prior to the certification tests are also included in Appendix 2.12.4. These tests describe the improvements to the Traveller XL design, substantiate the basis for the most severe hypothetical accident condition, and were used to validate the computer simulations.

Because so much work was involved in developing the Traveller XL shipping package, the following table summarizes its development from the first prototype through the Certification Test Unit, or CTU. As can be seen, satisfying the thermal test requirements proved more difficult than expected. However, the culmination of the development effort has yielded a shipping package that has been thoroughly tested and meets the requirements of both 10 CFR 71 and TS-R-1.

Table 2-5 Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance
Prototype-1 Drop testing: Jan 27-28, 2003 Burn Testing: Feb 28, 2003	Objective: FEA validation - 9 m low angle slap down (14.5 degrees) - 9 m high angle (71 degrees) - 1 m pin puncture (through CG, low angle) - 35 minute pool fire burn test.	- Outerpack – Satisfied requirements. Minor, local damage only. - Clamshell – Satisfied requirements for 9 m low angle test. Failed requirements for 9 m high angle test. Satisfied 1 m pin puncture test.	Outerpack failed to prevent ignition of polyethylene sheets in one location. Clamshell temperature away from interior combustion satisfied fire requirements.

Comments:

The Traveller XL Prototype-1 demonstrated robust structural performance, except for the Clamshell head(s) attachment which was not adequate. The most probable root cause of ignition of polyethylene sheeting was polyurethane foam combustion products entering the inside of the Outerpack as a result of holes drilled into inner Outerpack shell for thermocouples. No seals were used in the Outerpack for conservatism.

Fire testing failed to prevent ignition of the combustible materials in the Outerpack. However, the components not adjacent to the internal fire remained well within thermal limitations, thus, demonstrating that the Outerpack had sufficient thermal resistance to external heat flow into package.

Design Changes as a Result of Testing:

Additional bolts were added to secure the top Clamshell head for Prototype-2 testing (see below).

The package was subjected to the applicable tests for Normal and Hypothetical Accident conditions as described below. Following this series, the package was modified again to assess the robustness of the design. The center Outerpack hinge bolts were removed (1 of 3 bolts) from each hinge section. The number of locking pins on the Clamshell latches was also reduced, from 18 to 12.

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance
Prototype-2 Drop Testing: Jan 30, 2004 Burn Testing: N/A	- 1.2 m low angle slapdown (20 degrees) - 1 m pin puncture (through CG, low angle) - 9 m high angle (72 degrees) **Bolts and locking pins removed (described above)** - 9 m end drop (bottom end down) - 9 m horizontal (feet down) - 9 m horizontal (side down)	- Outerpack – Satisfied requirements for all 9 m drops and pin puncture tests. Minor, local damage only. - Clamshell – Satisfied requirements for first 9 m drop. Bottom head separated in second 9 m drop (bottom end drop) because the fuel assembly was not properly seated against bottom Clamshell head as a result of prior drop. No other significant damage.	- Prototype 2 was not subjected to HAC fire testing.

Table 2-5 (cont.) Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance

Comments:

The performance of the Prototypes (1 & 2) associated with the first testing campaign clearly demonstrated the robustness of the Overpack and Clamshell (except for the Clamshell head attachments). In all, six (6) drops were performed on 2 full-scale prototypes from 9 m. The Outerpack retained its overall integrity and functionality. Most importantly, all design features important to criticality safety performed as intended. Moderator blocks and simulated borated aluminum plates remained intact and attached to their respective structural components.

Design Changes as a Result of Testing:

Based on the robust structural performance of the Prototype units, several design changes were made to the Traveller XL for subsequent testing in the second test campaign. The Traveller units fabricated for the second campaign were called the Qualification Test Units, or QTUs. A total of two units were fabricated and tested. The significant changes to the QTUs were as follows:

1. The Outerpack stainless steel shells were reduced from 11 gauge (0.1196 in., 3.04 mm) to 12 gauge (0.1046 in., 2.66 mm). This change was made primarily to lower weight and reduce excessive structural margin.
2. The hinge bolts were reduced in both number and size, from ten 7/8" (2.22 cm) diameter bolts to ten ¾" (1.91 cm) bolts. This change was made to reduce excessive design margin.
3. A total of 2 seal materials were added to the design to act as: 1) an environmental seal, and 2) to minimize hot gases from entering the Outerpack seams.
4. The Outerpack leg structure, circumferential stiffeners, stacking brackets, and forklift pocket structures were changed. These changes were made for simplified manufacturing purposes and to reduce excessive design margin.
5. The polyurethane foam density of the center section of the package was reduced from 11 pcf to 10 pcf. The axial limiter foam sections of the package were also reduced from 16 pcf to 14 pcf. This change was made to lower the impact deceleration, and therefore loads experienced by the Clamshell.
6. The Clamshell extrusions were made thicker, from a nominal 0.375" (0.95 cm) to 0.438" (1.11 cm). This change was made primarily to eliminate welding of the heads to the extrusions. Bolted connections were utilized to attach the heads.
7. The welded simulated poison plates were redesigned for a bolted connection. This change was made to reduce the distortion of the aluminum Clamshell extrusions due to welding.
8. The Clamshell door locking latches were redesigned for quarter-turn nuts. This change was made for manufacturing and aesthetic purposes.
9. The Clamshell axial restraint system for restraint of the fuel assembly was redesigned. This change was made to simplify the fuel handling.

<table>
<tr><th colspan="4">Table 2-5 (cont.) Summary of the Development of the Traveller</th></tr>
<tr><th>Traveller XL</th><th>Test Sequence(s)</th><th>Structural Performance</th><th>Fire/Thermal Performance</th></tr>
<tr><td>QTU-1
Drop Testing: Sep 11, 2003
Burn Testing: Sep 15, 2003</td><td>- 1.2 m low angle slapdown (10 degree)
- 9 m high angle (72 degrees)
- 1 m pin-puncture (83 degrees at bottom end)
- 37 minute pool-fire burn test.</td><td>- Outerpack – Satisfied requirements for both drops and pin puncture tests. Minor, local damage only.
- Clamshell – Satisfied requirements for both drops and pin puncture tests.</td><td>Failed to prevent ignition of the polyethylene sheeting inside the Outerpack. Temperatures inside the Outerpack exceeded design limits. The package was extinguished approximately 1 hour after the conclusion of the pool fire testing.</td></tr>
<tr><td colspan="4">Comments:
The Traveller XL QTU-1 demonstrated robust structural performance. No Outerpack bolts failed. The Outerpack did not separate, and the pin puncture did not perforate the inner or outer shells nor did it effect the Clamshell in any detrimental way.
One hour after the pool fire, the package burning was extinguished. Upon inspection of the QTU-1 unit, it was determined that excessive distortion of the Outerpack shells between the hinges, allowed sufficient hot gases to ignite the polyethylene sheeting on the top half of the Outerpack. The burnt polyethylene sheeting was directly in line with the gaps in between the hinges. The burnt zones (4) were located only on the upper half of the Outerpack. This is most likely due to the flanges on the mating Outerpack halves which preferentially directs incoming gases to the upper portion of the Outerpack.
Design Changes as a Result of Testing:
Based on unsuccessful fire testing of the QTU-1 unit, the QTU-2 unit was modified for improved thermal performance. Since the QTU-2 had already been drop tested in accordance with 10 CFR 71, and TS-R-1 requirements, only minor modifications were deemed acceptable. Only changes considered for the QTU-2 were ones that would not have affected the drop characteristics and performance. The changes made to the QTU-2 unit subsequent to drop testing are listed as follows:
1. The 10 short Outerpack hinge sections were removed and replaced with 8 (four per side) long hinge sections that butted together forming a continuous hinge covering essentially all of the Outerpack mating seams.
2. The polyethylene moderator sheeting (both top and bottom sections) was covered with 26 gage stainless steel sheet metal. This sheet material was welded to the inner shells of the Outerpack along the sides of the covers, the ends (both top and bottom) were sealed with adhesive. The coverings therefore, were not completely welded closed.</td></tr>
<tr><td>QTU-2
Drop Testing: Sep 11, 2003
Burn Testing: Oct 20, 2003</td><td>- 1.2 m low angle slapdown (10 degrees)
- 9 m end drop (bottom end down)
- 1 m pin puncture (22 degrees through CG)
- 32 minute pool-fire burn test.</td><td>- Outerpack – Satisfied requirements for both drops and pin puncture tests. Minor, local damage only.
- Clamshell – Satisfied requirements for both drop tests and thermal tests. No failures were noted in any structure, or fasteners. The maximum temperature of the Clamshell and its contents never exceeded design limits</td><td>- Failed to prevent ignition of the polyethylene sheeting inside the Outerpack. However, the maximum temperature of the Clamshell and contents remained below 200°C. The package was extinguished approximately 7 hours after the conclusion of the pool fire testing.</td></tr>
</table>

Table 2-5 (cont.) Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance

Comments:

The Traveller XL QTU-2 demonstrated robust structural performance. No Outerpack bolts failed. The Outerpack did not separate, and the pin puncture did not perforate the inner or outer shells nor did it effect the Clamshell in any detrimental way.

Seven hours after the pool fire, the package burning was extinguished. During this seven hour period there was continuous low level smoldering. Upon inspection of the QTU-2 unit, it was determined that ignition occurred at the bottom end of the package. This was most likely caused by distortion of the Outerpack halves in the area of the bottom end where the impact limiter warped away from the top Outerpack half during the fire. The continuous hinge sections also did not cover the last 3 inches of the Outerpack seams on both sides of the package, which may have allowed additional hot gases to enter the package. The hot gas ingress occurred at a location were there was exposed polyurethane foam (the inner axial limiter foam) due to the thin stainless steel limiter cover being punched out by the Clamshell. This was an expected consequence of the bottom end drop.

The long sheet metal covers which were welded along their sides but applied adhesive at the ends did not perform as anticipated. The covers distorted during the testing and opened the adhesive joint. This allowed the polyethylene moderator to ignite. The areas around the shock mounts also were not covered with sheet metal thus exposing the moderator to the conditions inside the Outerpack. These exposed areas showed signs of burning in post-test examinations.

The QTU-2 test demonstrated that the polyethylene sheeting must be completely welded, or “canned”, by sheet metal to prevent ignition. However, this test was further evidence that the “bulk” heating of the inside of the Outerpack was acceptable, even with burning occurring within the Outerpack. This is a result of the fact that there is insufficient oxygen to support large amounts of burning. It was estimated that over the 7.5 hours of total burning, only about 10-15% of the moderator material was consumed.

Design Changes as a Result of Testing:

Based on the structural success of the QTU units and the thermal failures of the units, several changes were made to the design. These changes are listed below:

1. The 26 gage moderator sheet metal covers were redesigned so that the polyethylene was completely encapsulated by sheet metal. This mandated the use of sheet metal “cones” around each shock mount. Additionally, thin ceramic insulating material was incorporated between the moderator sheet and the metal covers, around the cones, and over a length of 30 inches at both the top and bottom ends. The ceramic “paper” is nominally 0.06 inches (0.15 cm) in thickness. Ceramic felt was also incorporated to fill the voids under the shock mount cones and at the ends of the moderator sheets.
2. The thin sheet metal impact limiter cover which were design to be punched out by high angle Clamshell impacts were redesigned to have thicker (0.25", 0.64 cm) puncture-resistant plates. These “pillows” were separate structures that were tested in a separate series of mechanical and thermal tests prior to CTU testing. The purpose of the pillows was to prevent polyurethane foam from becoming exposed to the inside of the outerpack, even in end drops. The pillow also incorporated a thick (0.25", 0.64 cm) plate at its base to act as a heat capacitor for incoming heat during the fire testing. Finally, the void space between the pillow and the outer sections of the impact limiters was filled with ceramic felt and paper to further reduce the heat load to the pillows and the internal contents of the Outerpack.
3. The foam density within the inner section of the impact limiters, or pillows, was reduced from 7 pcf to 6 pcf to allow more crushing of the foam. This change was made to lower the impact forces on the Clamshell and its contents.

Table 2-5 Summary of the Development of the Traveller (cont.)

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance
4. The four (4) long Outerpack hinge sections were lengthened to cover all of the Outerpack seams. There existed a nominal 3 inch (7.6 cm) uncovered section at the bottom end. 5. The bottom limiter cover which curves around the bottom impact limiter was extended an additional 1.5 inches axially. Ribs (or lips) were added to this cover, and to the bottom limiter, to further reduce the ingress of hot gases. 6. The foam density in the outer sections of impact limiters was increased from 14 pcf to 20 pcf to reduce the heat flow through these sections. 7. The polyethylene moderator sheets were redesigned for manufacturing purposes. 8. The silicone rubber Omega seal, was replaced with acrylic impregnated fiberglass braided tubing. This change was made to eliminate a potential source of combustion inside the Outerpack. The design changes listed above were retrofitted onto the QTU-1 unit (which had already been burned). The QTU-1 unit was then instrumented and taken through a series of fire tests in an effort to quantify the thermal design margins associated with these design changes. This testing was considered necessary to quantify the thermal design margins before the final Certification Test Unit (CTU) test article was tested. The modified unit was tested twice. It was first burned for 40 minutes, then it was re-burned for another 30 minutes the following day. The results of the tests were excellent. The impact limiter pillow temperature never exceeded 120°C, and the data confirms the primary heating to the inside of the Outerpack is by conduction. Based on the successful testing of the modified QTU-1 article, the design changes were incorporated in the manufacturing of the Traveller XL CTU package			
CTU Drop Testing: Feb 5, 2004 Burn Testing: Feb 10, 2004	- 1.2 m low angle slapdown (9 degrees) - 9 m end drop (bottom end down) - 1 m pin puncture (21 degrees through CG, directly onto Outerpack hinge) - 32 minute pool-fire burn test.	- Outerpack – <u>Satisfied</u> requirements for both drops and pin puncture tests. Minor, local damage only. - Clamshell – <u>Satisfied</u> requirements for both drop tests and thermal tests. The Clamshell retained its shape and remained closed and latched after drop testing.	Clamshell – <u>Satisfied</u> requirements for fuel containment and criticality safety. The Clamshell and its contents remained below a maximum of 150°C.
The Traveller XL CTU demonstrated robust structural performance. No Outerpack bolts failed and the Outerpack retained its circular pre-test shape. The Outerpack did not separate, and the pin puncture did not perforate the inner or outer shells nor did it affect the Clamshell in any detrimental way. Minor weld failures on the Outerpack, in the region near the impact, were observed in post-test examinations. These failures had negligible effect on the performance of the CTU. The two (2) quick release pins on the cover lips detached during the drop test, therefore, they could not be used where they were intended, in the burn test (as such, they were not re-installed for the burn testing).			

Table 2-5 (cont.) Summary of the Development of the Traveller

Traveller XL	Test Sequence(s)	Structural Performance	Fire/Thermal Performance

The impact limiter pillows performed as intended, however, they did not crush as much as intended due to the inherent axial flexibility of the 17x17 XL fuel assembly. The moderator sheeting remained completely contained within the sheet metal covering. A small brown spot was observed on the back side of one moderator sheet attached to the Outerpack top half. A very small amount of flow occurred away from the hot spot. This melt spot was small, affecting only a few cubic centimeters of material.

The Clamshell was found intact and closed, and the simulated poison plates maintained their attached position with very little distortion. Minor damage was observed at the location of the impact with the pillow, however, the damage had negligible effect on the performance of the Clamshell. All closure nuts remained intact with no signs of distortion or stress.

The most significant observation from the post-test examinations were 20 cracked fuel rod bottom end plug welds. These cracks occurred in the regions corresponding to the corners of the bottom nozzle. At these corners, the buckled bottom nozzle has steep faces (in excess of 45 degrees), which was exacerbated by the characteristically long legs of the 17XL assembly. The angled faces apply a side force to the local fuel rods as they are decelerated in the impact. The largest crack occurred in a fuel rod located in the outermost row within the assembly. The crack in the rod had a maximum width of approximately 0.075" (1.91 mm). This width is not sufficiently large enough for loss of fuel from the rod. Further, in all cases of cracked rods, the bottom end plugs did not separate. Therefore, fuel pellets are prevented from exiting any of the cracked rods.

Design Changes as a Result of Testing:

The CTU satisfied the HAC drop-test and burn-test requirements in all aspects. However, as with any development program, improvements can be envisioned after every series of tests. Based on the results of the CTU tests, several minor changes shall be incorporated into production units to enhance the performance of the package. There changes do not change the performance or characteristics of the package, but merely improve the safety margin of the package by incorporating rather obvious improvements as listed below. The basis for the change is also listed below:

1. The studs which hold the moderator blocks to the upper Outerpack half failed during the drop testing. The moderator remained contained within the sheet metal covering. However, the number of 3/8" (0.95 cm) diameter studs shall be increased by 50% on the top Outerpack assembly only.
2. The bottom impact limiter pillow is welded at the top plate to the Outerpack inner plate. This weld is design to break in a high angle impact. It performed well in the drop test, however, it did not completely break. This joint shall be redesigned with a small groove cut into the inner plate to form a weakened break point. The break shall therefore not necessarily occur at the weld location.
3. The quick release pins used to secure the bottom end seam flange cover failed during drop testing but had negligible effect on the performance (intended for thermal performance only). Therefore, they were not used in the thermal test and will not be used in production units.

The figure below (Figure 2-1B) shows the impact limiter, or Pillow, assembly (shown without insulation). This assembly is shown installed in the Traveller package bottom (the configurations are the same for STD and XL packages) in Figure 2-1C. The weld between the bottom plate (yellow) and the puncture plate (red) is also shown. During testing this weld failed as expected, however, it did not completely allow the components to separate. This design change weakens the bottom plate by reducing its thickness to a nominal 0.025" thickness, as shown in Figures 2-1D and 2-1E. A .25 inch wide channel was added to weaken the part.

Table 2-5 (cont.)	*Summary of the Development of the Traveller*		
Traveller XL	***Test Sequence(s)***	***Structural Performance***	***Fire/Thermal Performance***

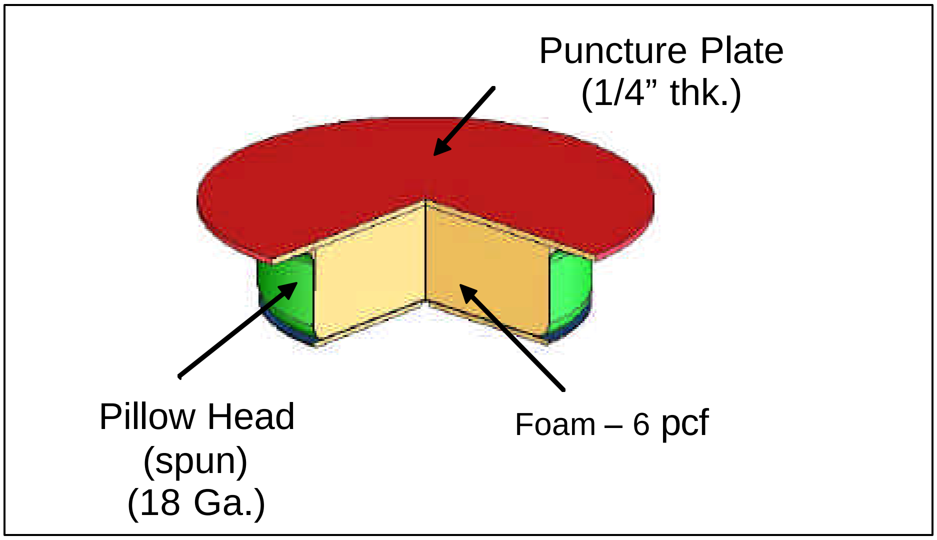

Figure 2-1B Impact Limiter "Pillow" Assembly

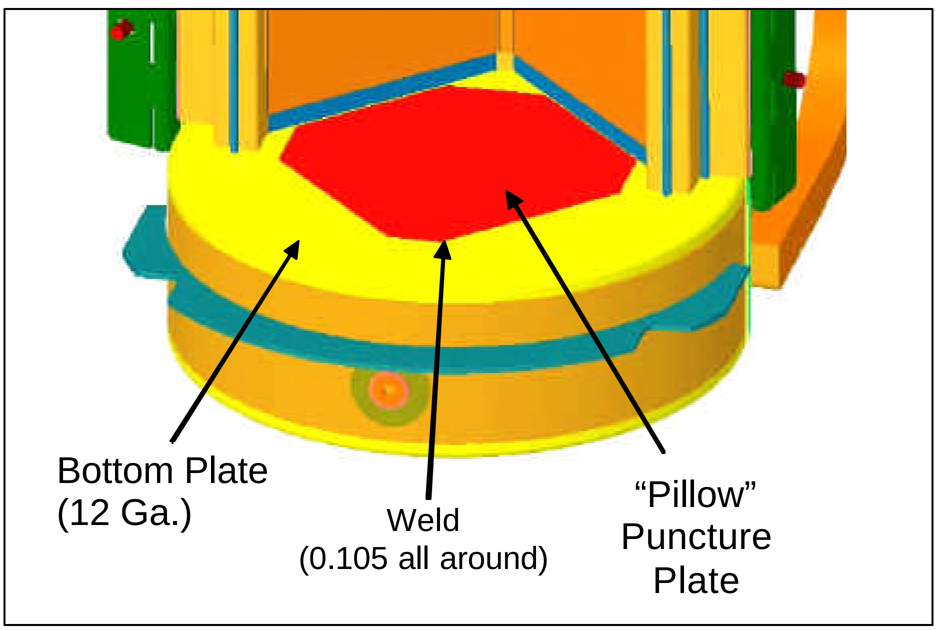

Figure 2-1C Container Bottom End

Table 2-5 (cont.) *Summary of the Development of the Traveller*

Traveller XL	*Test Sequence(s)*	*Structural Performance*	*Fire/Thermal Performance*

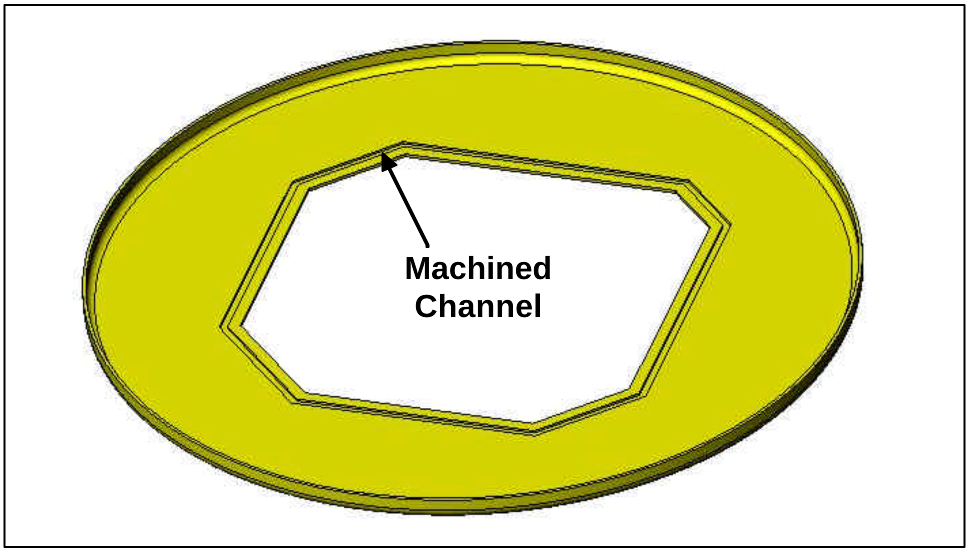

Figure 2-1D Bottom Plate (Viewed from Inside)

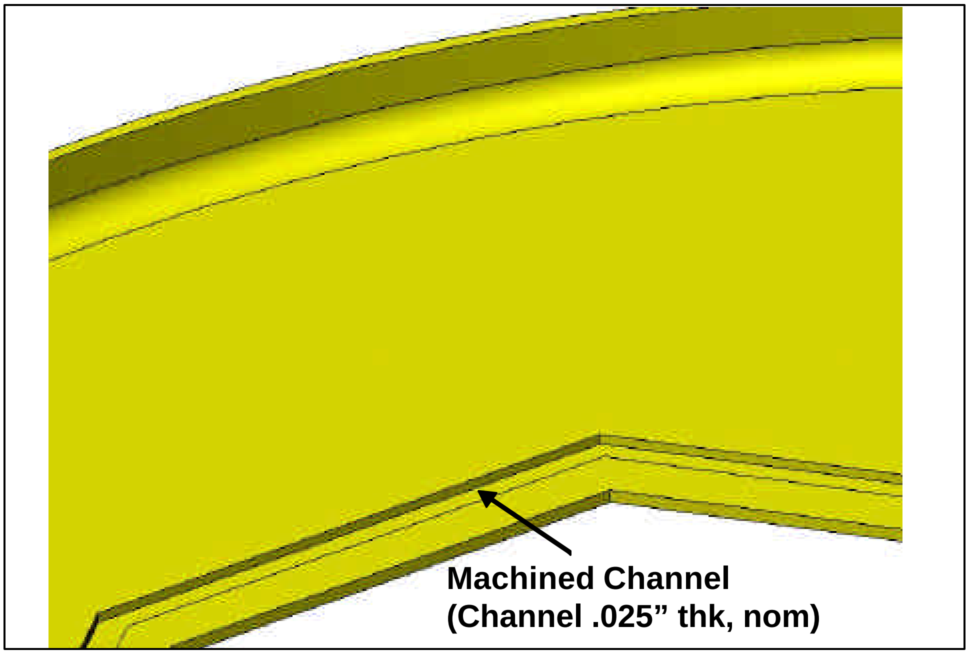

Figure 2-1E Bottom Plate – Viewed from Inside

Table 2-5 (cont.) ***Summary of the Development of the Traveller***

Traveller XL	***Test Sequence(s)***	***Structural Performance***	***Fire/Thermal Performance***

The CTU design included a pinned connection (2 quick release pins – 0.5" diameter) between Outerpack halves at the bottom end of the package. Quick release pins were designed to help prevent the halves from warping and opening a gap locally during fire testing. Figure 2-1F shows the location of the quick release pins. During drop testing, the pins failed, therefore, they could not be used in the fire testing.

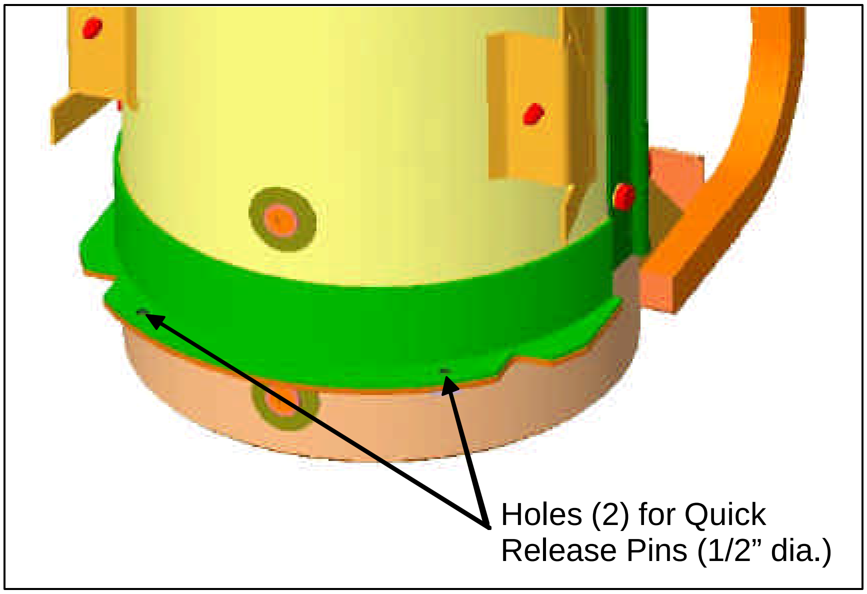

Figure 2-1F CTU Package Bottom End

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2.7.1 Free Drop

Subpart F of 10 CFR 71, TS-R-1 (727) requires that a 9-meter (30 foot) free drop be considered for the Traveller series of packages. The free drop is to occur onto a flat, essentially unyielding, horizontal surface, and the package is to strike the surface in an orientation for which the maximum damage is expected. The free drop is addressed by test, in which the most severe orientation is used. The free drop precedes both the puncture and fire tests. The ability of the Traveller packages to adequately withstand this specified drop condition is demonstrated via drop testing of the full-scale Traveller XL Certification Test Unit (CTU). The Traveller XL variant bounds the shorter and lighter Traveller STD design.

2.7.1.1 Technical Basis for the Free Drop Tests

To properly select a worst case package orientation for the 9 m (30 feet) free drop event, the foremost item that could potentially compromise the criticality control integrity of the Traveller series of packages must be clearly identified.

The criticality control integrity may be compromised by four methods: 1) excessive movement of the fuel rods such that they form a critical geometry, 2) damage/destruction of the borated aluminum and polyethylene sheeting, 3) degradation of the borated aluminum/polyethylene sheeting and/or 4) other structural damage that could affect the nuclear reactivity of an array of packages.

For the above considerations, testing and FEA predictive methodology must include orientations that affect the Clamshell geometry and integrity. Throughout the development of the Traveller XL, minor design changes were made to optimize the structural and thermal performance of the package.

A total of nine (9) 30 foot (9 m) free drops were performed using full-scale prototypes at a variety of orientations to determine the most severe orientation and to assist in benchmarking the computer simulation model. Based on these tests, and the predictions of the analytic analyses, it was determined that the most severe 9 m free drop orientation was a bottom-end down drop due to; 1) the relatively high deceleration, 2) the greatest opportunity for lattice expansion of the fuel, and 3) the greatest opportunity for fire damage as a result of the subsequent pool-fire thermal testing.

The bottom-down end drop causes the greatest damage to the axial impact limiters, or “pillows.” These pillows were incorporated as a re-design from QTU-2 testing whereby the Clamshell punched through the plate covering the inner section of the axial impact limiter. This exposed foam later burned within the interior of the Outerpack and ignited the moderator panels. The concept of a puncture plate was redesigned to incorporate a “puncture resistant” plate. The inner foam limiter was therefore protected by the puncture resistant plate (1/4" thk, 0.64 cm), and was enclosed by a spun metal “can” welded to the plate to completely seal the pillow assembly. CTU test results confirmed that no polyurethane foam was exposed as a result of the bottom-down end impact.

The long bottom nozzle “legs” associated with the Westinghouse 17x17 XL fuel assembly are considered the most severe because they allow considerable strain of the bottom nozzle (particularly the flow plate, or adapter plate) during a bottom-down end drop. The bowed adapter plate offers the greatest opportunity to damage fuel rods during the impact.

The top-down end drop produces significantly lower deceleration due to buckling of the axial clamp bolts. As these buckle, considerable energy is absorbed, thus lower the buckling of the top nozzle. By comparison, the bottom-down end drop is more severe.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, the Traveller XL CTU was tested for one specific, HAC 9 m (30 foot) free drop conditions: 1) End drop onto the bottom of the container. This single “worst case” 9 m drop is required. Numerous 9 m drops using full-scale prototypes were tested prior to CTU testing to determine the most severe orientation. The specific conditions for all full-scale prototype and CTU tests are summarized in Table 2-2 above.

2.7.1.3 Summary of Results from the Free Drop Tests

Successful HAC free drop testing of the Traveller XL CTU certification unit indicates that the various structural features are adequately designed to withstand the 9 m (30 foot) free drop event. The most important result of the testing program was the demonstrated ability of the bounding Traveller XL package to maintain its criticality safety integrity.

Significant results of the free drop tests, including the thermal test, are as follows:

1. There was no breach or distortion of the Clamshell aluminum container.
2. There was no evidence of melting or material degradation on the polyethylene sheeting.
3. The Outerpack remained closed and structurally intact.
4. A small number of rods (20) were cracked during drop testing (only seen in bottom-end drops).
5. Rod damage has been at the end of the rods only. No damage anywhere else.
6. None of the end plugs have separated from the rods.
7. No pellet material is lost from the cracked rods.

Further details of the free drop test results are provided in Appendix 2.12.4, Traveller Drop Test Results.

2.7.2 Crush

The crush test specified in 10 CFR §71.73(c)(2), TS-R-1 (727) is required only when the specimen has mass not greater than 500 kg (1,100 pounds), an overall density not greater than 1,000 kg/m^3 (62.4 lb/ft^3), and radioactive contents greater than 1,000 A2, not as special form. The gross weights of the Traveller packages are greater than 500 kg (1,100 pounds). Therefore, the dynamic crush test of 10 CFR §71.73(c)(2), TS-R-1 (727) is not applicable to the Traveller series of packages.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.71(c)(3), TS-R-1 (727). The puncture test involves a 1 m (40 inch) drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounting on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 inches) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 6 mm (1/4 inch). The minimum length of the bar is to be 20 cm (8 inches). The ability of the bounding Traveller XL packages to adequately withstand this specified drop condition is demonstrated via testing of numerous full-scale Traveller XL prototypes and the Certification Test Unit (CTU).

2.7.3.1 Technical Basis for the Puncture Drop Tests

To properly select a worst case package orientation for the puncture drop test, items that could potentially compromise criticality integrity of the Traveller package must be clearly identified. For the Traveller XL package design, the foremost item to be addressed is the integrity of the Clamshell and the neutron moderation and absorption materials (i.e., borated aluminum and polyethylene sheeting).

The integrity of the Clamshell and the criticality control features may be compromised by two methods: 1) breach of the Clamshell boundary, and 2) degradation of the neutron moderation/control materials due to fire.

For the above reasons, testing must consider orientations that attack the Outerpack closure assembly, which may result in an excessive opening into the interior for subsequent fire event, and/or the Clamshell which contains the fuel assembly. Based on prototype testing and computer simulations of the pin puncture event, the pin puncture has insufficient energy to cause significant damage to the Outerpack hinge closure system nor to the Clamshell (including components within the Clamshell).

The greatest possibility of cumulative damage to the package occurs when the pin puncture is located in within the area of impact of the 9m drop. These locations further attack the welded joints adjacent to the crushed area between the Outerpack outer shell and the end cap. Many pin puncture locations were tested in prototype testing, and all had insignificant impact on the structural and thermal performance of the package. See Table 2-2 above, and Appendix 2.12.4, Traveller Drop Test Results, for more information regarding pin puncture testing.

Based on the above discussion, the Traveller XL CTU was specifically evaluated at a "new" location. The pin puncture was located such that the pin impacted directly on an Outerpack hinge at a low impact angle. This test had not previously been performed, and it was desired to test the hinge's ability to take a pin impact and still perform its important function of thermally protecting the seam between Outerpack bottom and top assemblies. Section 3 describes how the hinge protects the seam in more detail.

2.7.3.2 Summary of Results from the Puncture Drop Tests

Successful HAC puncture drop testing of the CTU indicates that the various Traveller XL packaging features are adequately designed to withstand the HAC puncture drop event. The most important result of the testing program was the demonstrated ability of the bounding Traveller XL to maintain its structural integrity. Significant results of the puncture drop testing are as follows:

1. Minor damage to the Outerpack and Outerpack hinge
2. No affect on the structural or thermal performance of the package.
3. There was no evidence of separation of the Outerpack seam which would allow hot gases to enter the Outerpack.
4. No evidence of movement occurred that would have significantly affected the geometry or structural integrity of the Clamshell.
5. There was no evidence of loss of contents from the Clamshell due to the puncture events.
6. There was no evidence of deterioration of the polyethylene sheeting in the subsequent fire event.
7. There was no evidence of deterioration of the borated-aluminum sheeting (simulated) in the subsequent fire event.

Further details of the puncture drop test results are provided in Appendix 2.12.4, Traveller Drop Test Results.

2.7.4 Thermal

Subpart F of 10 CFR 71, TS-R-1 requires performing a thermal test in accordance with the requirements of 10 CFR §71.71(c)(4), TS-R-1 (728). To demonstrate the performance capabilities of the Traveller packaging when subjected to the HAC thermal test specified in 10 CFR §71.71(c)(4), TS-R-1 (727), a full-scale CTU was burned in a fully engulfing pool fire. The test unit was subjected to a 9 m (30 foot) free drop, and a 1.2 m (4 foot) puncture drop, prior to being burned, as discussed above. Further details of the thermal performance of the Traveller XL CTU are provided in Section 3, Thermal Evaluation.

Type K thermocouples were installed on the exterior surface of the packaging (each side, top, and bottom) to monitor the package's temperature during the test. In addition, passive, non-reversible temperature indicating labels were installed on the Clamshell, fuel assembly, and inner surfaces of the Outerpack.

The CTU was exposed to a minimum 800ºC (1,475ºF), 30-minute pool fire. As discussed in Appendix 2.12.4, Traveller Drop Test Results, the package was orientated such that the Outerpack was on its side. This orientation offered the greatest opportunity for formation of a chimney and thus result in maximum combustion of the Outerpack foam and degradation of the polyethylene sheeting.

Following the minimum 30-minute fire, the CTU was allowed to cool naturally in air, without any active cooling systems.

2.7.4.1 Summary of Pressures and Temperatures

The accident case pressure is assumed to be 0 psig since the Outerpack and Clamshell are not sealed.

The peak temperatures for the Clamshell, as recorded by five (5) temperature indicating strips, was 104ºC (217ºF). No loss of material was observed in the polyethylene material.

2.7.4.2 Differential Thermal Expansion

Fire testing of a full-scale Traveller XL package indicates that the stresses associated with differential thermal expansion of the various components are negligible.

2.7.4.3 Stress Calculations

Successful fire testing of a full-scale Traveller XL CTU package, as well as prior tested prototypes, indicates that the stresses associated with differential thermal expansion of the various packaging components are negligible.

2.7.4.4 Comparison with Allowable Stresses

As discussed in Section 2.7.4.3, Stress Calculations, further evaluation of stresses associated with differential thermal expansion for the various Traveller package components is not required.

Successful HAC thermal testing of the CTU indicates that the various Traveller packaging design features are adequately designed to withstand the HAC thermal test event. The most significant result of the testing program was the demonstrated ability of the Traveller XL CTU to maintain its criticality control integrity, as demonstrated by post-test inspection of; the moderator and poison materials, the remaining polyurethane foam, and the integrity of the Clamshell.

Further details of the thermal test results are provided in Appendix 2.12.4, Traveller Drop Tests Results and Section 3, Thermal Evaluation.

2.7.5 Immersion – Fissile Material

Subpart F of 10 CFR 71 requires performing an immersion test for fissile material packages in accordance with the requirements of 10 CFR §71.73(c)(6), TS-R-1 (733). Because of the seal configuration (see Section 1, General Information), the Traveller STD and Traveller XL packages are not leak-tight under external overpressure. Under the immersion test, water will fill all internal void space. Because of the pressure equalization, the packaging structure is therefore not subjected to loading during these tests.

2.7.6 Immersion – All Packages

Subpart F of 10 CFR 71 requires performing an immersion test for fissile material packages in accordance with the requirements of 10 CFR §71.73(c)(6), TS-R-1 (729). Because of the seal configuration (see Section 1, General Information), the Traveller STD and Traveller XL series of packages are not leak-tight under external overpressure. Under the immersion test, water will fill all voids. Because of the pressure equalization, the packaging structure is therefore not subjected to loading during these tests.

As the package model criticality study assumes the worst-case flooding scenario, the Traveller XL CTU is exempted from this water immersion test.

2.7.7 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of the free drops, puncture drop, and thermal tests were satisfactorily withstood by the Traveller XL CTU. Subsequent examinations of the CTU confirmed that integrity of the criticality control components was maintained throughout the test series. The geometry of the Clamshell remained essentially unchanged from the pretest condition. In addition, the Fuel Assembly was well protected and experienced damage that was within acceptance criteria. Therefore, the requirements of 10 CFR §71.73, TS-R-1 (726-729) have been adequately satisfied.

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

Not applicable.

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL FOR AIR TRANSPORT

Application to be made at a later date.

2.10 SPECIAL FORM

The contents of the Traveller series of packages do not classify as special form material.

2.11 FUEL RODS

In the Traveller XL and STD packages, the fuel rods within the package provide containment for the nuclear fuel. This containment was successfully demonstrated in 3 full-scale test campaigns comprising a total of nine (9) 30 foot free drops, and the corresponding 1.3 meter free-drops and pin puncture tests. These tests resulted in 100% containment of the fuel pellets within rod of every fuel assembly.

For all 9-meter drop test orientations except for the bottom-down end drop (long axis of package aligned with the gravity vector), every fuel rod survived with no damage except slight to moderate buckling of the cladding. Rod pressure test sampling was routinely performed on these fuel assemblies. Except for the bottom-down end drop, all of the rods sampled remained intact and pressurized. All rods visually appeared in excellent condition.

A total of two (2) full-scale Traveller XL packages (QTU-2 and CTU) were tested in a bottom-down end drop orientation. Both of these fuel assemblies (dummy Westinghouse 17x17 XLs) experienced a small percentage of rods with cracked welds in the location of the bottom end plug. In the worst case assembly (CTU), post-test inspection of the fuel assembly indicated that approximately 7.5% of the fuel rods were visibly cracked at the end plug weld zone. The average magnitude of the crack widths measured approximately 0.030 inches (0.76 mm) encompassing about one-half of a rod diameter. This minor cracking is considered insignificant since fuel pellets of diameter 0.374 inches (9.50 mm) are approximately 12.5 times larger than the average visible crack widths. A crack width of 0.075 inches (1.91 mm) was the largest observed. This width is not sufficient for fuel pellets to escape. Therefore, the containment system satisfies its requirement of containing loss of fuel.

Due to the nature of the bottom-down end impact, the fuel rod array is tightly packed and forced into the bottom nozzle. As the bottom nozzle buckles, the rods located nearest the corners of the adapter plate experience a side loading due to the deformed shape of the plate. This moment is sufficient to crack the weld, however, it is clearly not sufficient to completely break off the bottom end plug since the array of rods is so tightly packed. No complete separation of the bottom end plug was observed in any fuel rods for both fuel assemblies. Therefore, the fuel pellets are safely contained within each fuel rod. Further details can be found in Appendix 2.12.4, Traveller Drop Tests Results.

2.11.1 Rod Box

The Traveller Clamshell is designed to accommodate PWR fuel assemblies. To accommodate loose fuel rods, two rod storage containers have been examined. One, is a 304 stainless steel rod pipe with a maximum diameter of 6.625 inches (6" Schedule 40 pipe), length of 168 inches, and a total weight of 635 lbs (loaded). The second option is a 304 stainless steel box width with a 5.12 inches cross-section. This box is 170.5 inches long and weighs 660 lbs loaded. Other optional designs are being examined which would reduce total length to 169 inches to allow use with the Traveller STD package.

The rod pipe and rod box are both designed to be contained within the Clamshell and restrained axially and radially. Although the rod box has a smaller wall thickness than the tube (0.059 vs 0.280 inches), both are substantially stiffer than the PWR fuel assemblies that the Clamshells normally carry. This, combined with the substantially lower weight of the loaded rod pipes or boxes (660 lb for the rod box vs. 1753 lbs for the fuel assembly used in the drop testing described) make accident scenarios with the rod pipe or rod box less challenging. The rod pipe or box, reinforce the Clamshell to prevent change in fuel geometry. The lower weight, reduces loads on Clamshell and Outerpack. The lower fuel load, reduces criticality concerns. It was therefore concluded that the Traveller package with a rod pipe or rod box is bounded by the CTU tests described.

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2.12 APPENDIX

2.12.1 Container Weights and Centers of Gravity

2.12.2 Mechanical Design Calculations for the Traveller XL Shipping Package

2.12.3 Drop Analysis for the Traveller XL Shipping Package

2.12.4 Traveller Drop Tests Results

2.12.1 CONTAINER WEIGHTS AND CENTERS OF GRAVITY

2.12.1.1 Container Weights

This section provides the Traveller XL and Traveller STD estimated weight breakdown and centers of gravity for each package.

Table 2-6 Summary of Traveller STD and Traveller XL Design Weights

	Traveller STD	Traveller XL
Outerpack Weight, lb (kg)	2368 (1074)	2633 (1194)
Max. Fuel Assembly Weight, lb (kg)	1650 (748)	1971 (894)
Clamshell Weight, lb (kg)	378 (171)	467 (212)
MAX. TOTAL WEIGHT, lb (kg)	4396 (1994)	5071 (2300)
DESIGN TARE WEIGHT, lb (kg)	2850 (1293)	3155 (1431)
DESIGN and LICENSING BASIS GROSS WEIGHT, lb (kg)	4500 (2041)	5100 (2313)

2.12.1.2 Centers of Gravity

This section provides the location of the center of gravity for empty Traveller XL and Traveller STD packages.

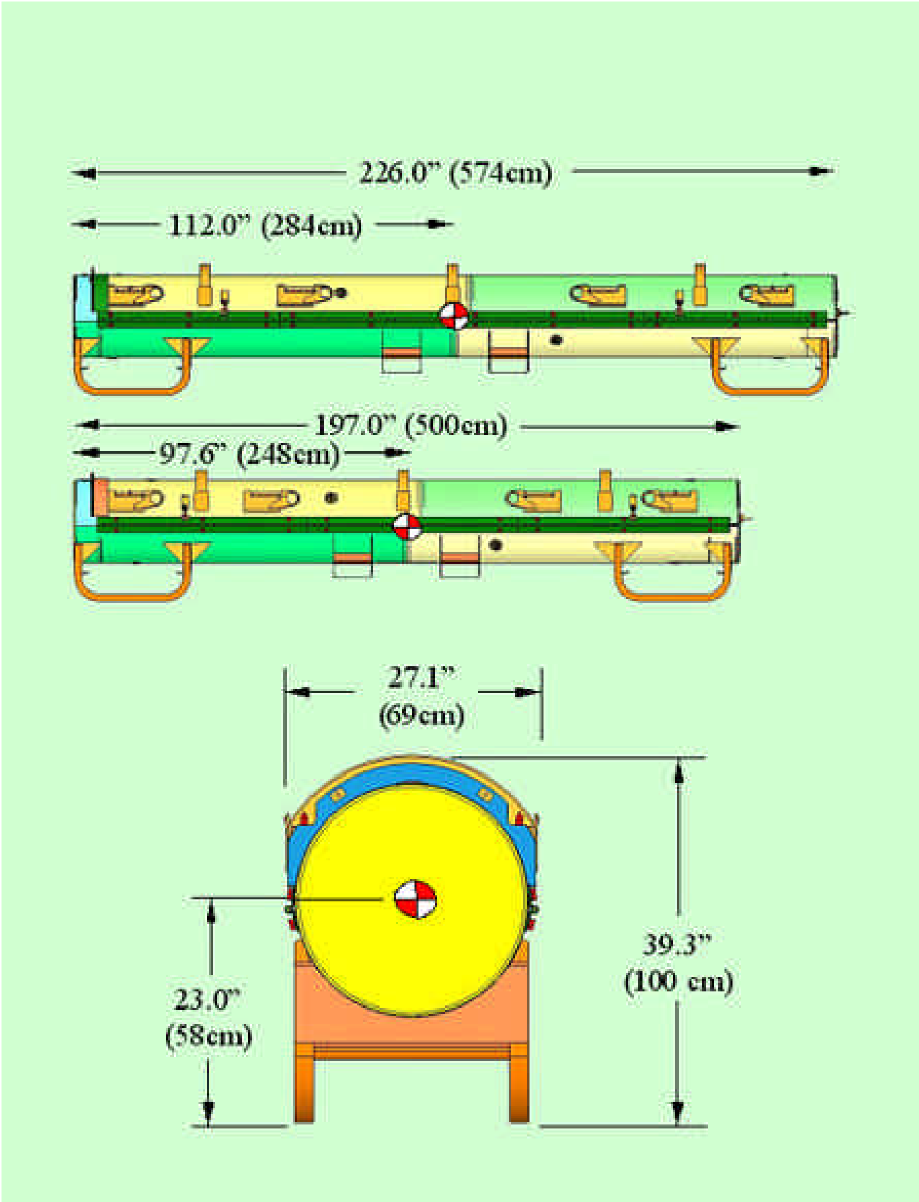

Figure 2-2 Traveller XL and Traveller STD Dimensions and Center of Gravity (Note: End View is Common to both Models)

2.12.2 MECHANICAL DESIGN CALCULATIONS FOR THE TRAVELLER XL SHIPPING PACKAGE

During Traveller package development, normal transport and hypothetical accident condition testing were performed to demonstrate package compliance to test conditions described in 10 CFR 71 and TS-R-1. For those requirements not demonstrated by testing, a mechanical analysis was performed to demonstrate package compliance. This section outlines the non-tested requirements to be satisfied and provides an analysis for each requirement.

The Traveller XL package is depicted in Figure 2-3. The exterior view of the Outerpack is shown. The internal packaging including the Clamshell is shown in Figure 2-4. The Traveller XL package structurally and mechanically bounds the Traveller STD package because it is more massive and longer than the Traveller STD. Additionally, the computer simulations and full-scale testing of the Traveller XL units demonstrate a robust design with considerable safety margins with respect to all structural and mechanical requirements.

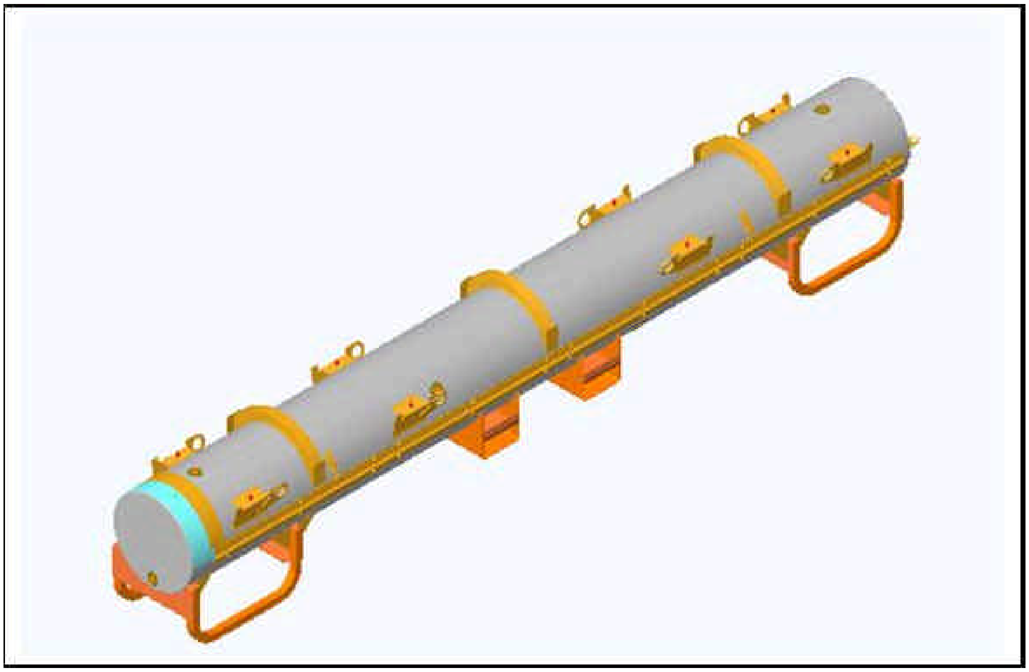

Figure 2-3 Westinghouse Fresh Fuel Shipping Package , the Traveller XL

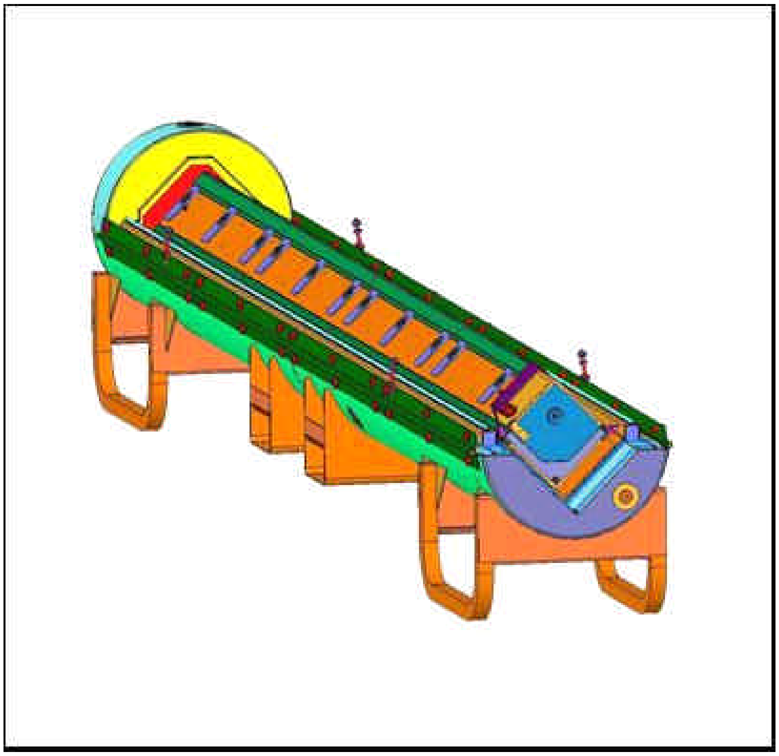

Figure 2-4 Internal View of the Traveller Shipping Package

2.12.2.1 Analysis Results and Conclusions

These analyses were performed to demonstrate Traveller XL package compliance to the mechanical requirements described in 10 CFR 71 and TS-R-1 for which no formal testing was conducted. These calculations bound the lighter, shorter Traveller STD unit. The applicable requirements are summarized in Table 2-7 below. The results of the design calculations (where applicable), acceptance criteria, and conditional acceptance are shown in Table 2-8. Based on the results in Table 2-8, the Traveller package is shown to be compliant to mechanical requirements described in 10 CFR 71 and TS-R-1.

Table 2-7 Summary of Regulatory Requirements for Mechanical Analysis

Requirement Description	US NRC Requirement	1996 IAEA Requirement	Applicable Condition
Lifting attachments	10 CFR 71.45(a)	TS-R-1, Paragraph 607	General Package Standard
Tie-Down devices	10 CFR 71.45(b)(1)	TS-R-1, Paragraph 636	General Package Standard
Design temperatures between –40°F (-40°C) and 158°F (70°C)	10 CFR 71.71(c)(1,2)	TS-R-1, Paragraphs 637 and 676	General Package Standard
Internal/External Pressure	10 CFR 71.71(c)(3,4)	TS-R-1, Paragraph 615	Normal transport condition
Vibration	10 CFR 71.71(c)(5)	TS-R-1, Paragraph 612	Normal transport condition
Water spray	10 CFR 71.71(c)(6)	TS-R-1, Paragraph 721	Normal transport condition
Compression/Stacking test	10 CFR 71.71(c)(9)	TS-R-1, Paragraph 723	Normal transport condition
Penetration	10 CFR 71.71(c)(10)	TS-R-1, Paragraph 724	Normal transport condition
Immersion	10 CFR 71.73(c)(6)	TS-R-1, Paragraph 729	Accident transport condition

The results of the design calculations (where applicable), acceptance criteria, and conditional acceptance are shown in Table 2-8. Based on the results in Table 2-8, the Traveller package is shown to be compliant to mechanical requirements described in 10 CFR 71 and TS-R-1. Where the design features of the Traveller eliminate design concerns (i.e., package tie-downs, internal pressure, etc.) detained stress calculations were not performed.

Table 2-8 Summary of Traveller Mechanical Analysis

Requirement Description	Allowable Design Value(s) or Acceptance Criteria	Calculated Value	Acceptable
Lifting attachments	Tensile Yield Stress, σ_y < 30 ksi Shear Yield Stress, τ_y < 18 ksi Weld shear Yield Stress, τ_y < 12 ksi Hoist Screw Shear Stress, τ < 60 ksi	Hole tear: τ = 5.1 ksi< 18 ksi Weld: τ = 9.5 ksi< 12 ksi (Alt. 8.1 ksi< 12 ksi) Hoist: τ = 49.4 ksi< 60 ksi	Yes, for all
Tie-Down devices	*NA*	No tie down systems on package	Yes
Design temperatures between –40°F (-40°C) and 158°F (70°C)	No brittle fracture No impact from Differential Thermal Expansion (DTE)	No Impact	Yes
Internal/External Pressure	*NA* σ_y < 30 ksi	No stress developed	Yes
Vibration	*NA*	No impact, 41 Hz > 3.7-8 Hz	Yes
Water spray	*NA*	No impact	Yes
Compression/ Stacking test	Weld shear Yield Stress, τ_y < 12 ksi Critical Buckling, F < P_{cr}	4.0 ksi < 12 ksi Outerpack; 25.5 ksi < 78.6 ksi Leg Support; 3.2 ksi < 26.9 ksi	Yes, for all
Penetration	*NA*	Bounded by 1.0m HAC pin-puncture; No perforation of outer skin.	Yes
Immersion	*NA*	No stress developed	Yes

Assumptions

The calculations to determine the maximum Outerpack allowable stresses for yield, shear, and weld shear are based on the properties of ASTM A240 Type 304 Stainless Steel. It is further assumed that the weld consumable possess greater mechanical properties than that of the base metal. Hence, the mechanical properties of the base metal will be employed for weld stress analysis. The reference drawings included in this analysis represent the Certification Test Unit (CTU) Traveller XL, which was fabricated for the drop and fire tests.

Acceptance Criteria

The Traveller package was structurally evaluated to demonstrate compliance to the conditions described in Table 2-7. The package's Outerpack structure is composed of ASTM A240 Type 304 Stainless steel. The mechanical properties are of listed below:

- Tensile strength, Minimum: 75 ksi
- Yield strength, Minimum: 30 ksi

For mechanical analysis where tensile, shear, or weld shear stresses were determined, the acceptance criteria was as follows:

- Maximum allowable tensile yield stress, σ_y = 30 ksi
- Maximum allowable shear stress, $\tau_{max} = .6\sigma_y$ = 18 ksi
- Maximum allowable weld shear stress, $\tau_{weld} = .4\sigma_y$ = 12 ksi

The material constant Young's Modulus for 304 Stainless steel is:

$$E = 29.4E6 \text{ psi}$$

2.12.2.2 Calculations

Nine mechanical conditions were evaluated for Traveller package. These conditions are outlined in Table 2-7. Standard engineering methods were used for these calculations.

2.12.2.2.1 Input

The design loads were determined according to the criteria described in 10 CFR 71 and TS-R-1, 1996 where appropriate. The Traveller XL package weight bounds the Traveller STD design as shown in Table 2-9. The total weights for each Traveller design include shipping components where applicable.

Table 2-9 Summary of Traveller STD and Traveller XL Design Weights

	Traveller STD	Traveller XL
Outerpack Weight, lb (kg)	2368 (1074)	2633 (1194)
Max. Fuel Assembly Weight, lb (kg)	1650 (748)	1945 (882)
Clamshell Weight, lb (kg)	378 (171)	467 (212)
MAX. TOTAL WEIGHT, lb (kg)	4396 (1994)	5071 (2300)
DESIGN TARE WEIGHT, lb (kg)	2850 (1293)	3155 (1431)
DESIGN and LICENSING BASIS GROSS WEIGHT, lb (kg)	4500 (2041)	5100 (2313)

Lifting – The lifting criteria is governed by 10 CFR 71.45(a) and TS-R-1, Paragraph 607. 10 CFR 71.45(a) states that any lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in its intended manner. In addition, it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71. The applied load to the package lifting attachments is then:

$$F_l = 3W_{T-2}$$

$$F_l = 3(5100)\ \text{lb}$$

$$F_l = 15{,}300\ \text{lb}$$

Tie-Downs – The tie-down requirements are described in 10 CFR 71.45(b) and TS-R-1, Paragraph 636. 10 CFR 71.45 states that a system of tie-downs that is a structural part of the package must be capable of withstanding, without generating stress in excess of its yield strength, a static force applied to the center of gravity having the following components:

- Vertical: 2 g
- Axial: 10 g
- Transverse: 5 g

Thus, the applied tie-down loads for the Traveller are:

- Vertical: 10,200 lb
- Axial: 51,000 lb
- Transverse: 25,500 lb

Design Temperatures between -40°F (-40°C) and 158°F (70°C) – The package must account for temperatures ranging from -40°F (-40°C) to 158°F (70°C) per TS-R-1 (637), and from -40°F (-40°C) to 100°F (38°C) per 10 CFR 71.71(c)(1,2). Thus, the bounding temperature range to consider for package design is -40°F (-40°C) to 158°F (70°C). The analysis of the Traveller package will consider the effects of temperature on thermally induced stress.

Internal/External Pressure – The package must account for the effects of external pressure conditions. The effects of reduced and increased external pressure are described in 10 CFR 71.71(c)(3,4) and TS-R-1 (615). The reduced external pressure is 25 kPa (3.5 psi) absolute, and the increased external pressure is 140 kPa (20 psi) as stated in 10 CFR 71.45.

Water Spray – A water spray test is required for the Traveller package to consider the effects of excessive rainfall on the structural integrity of the package. The water spray test is described by 10 CFR 71.71(c)(6) and TS-R-1 (721). The water spray test is to simulate a rainfall rate of approximately 5 cm/hr (2 in/hr) for at least one hour.

Compression/Stacking Test – The Traveller package must be subjected to a static compression test per by 10 CFR 71.71(c)(6) and TS-R-1 (723). Both regulations require that the applied load by the greater of the following:

An equivalent load of five times the mass of the package or the equivalent of 13 kPa (2 psi) multiplied by the vertically projected area of the package. Evaluating each case:

Case 1

The applied stacking force for case 1 is:

$$Fs = 5W_{T-2}$$

$$Fs = 5(5100)\ \text{lb}$$

$$Fs = 25{,}500\ \text{lb}$$

Case 2

The applied stacking force for case 2 is:

$$Fs = (Length)(OD)(P)$$

$$Fs = (226)(25)in^2(2)psi$$

$$Fs = 11{,}300\ \text{lb}$$

Thus, the applied stacking load is F_s = 25,500 lb.

Penetration – The penetration test is an impact test described by 10 CFR 71.71(c)(10) and TS-R-1 (724). The package must be subject to the impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1.25 in) diameter and a mass of 6 kg (13 lb) dropped from 1 m (40 in) onto the surface of the package that is expected to be the most vulnerable to puncture.

Immersion – The immersion test is a hypothetical accident condition test that evaluates the effects of static water pressure head on the structural integrity of the package. The test condition is described by 10 CFR 71.73(c)(6) and TS-R-1 (729). The regulations state that the package must be immersed under a head of water of at least 15 m (50 ft) for at least 8 hours in the most damaging orientation. For demonstration purposes, an external gauge pressure of 150 kPa (21.7 psi) is considered to meet the test conditions.

2.12.2.2.2 Lifting

Four Point Lift – The Traveller package is crane lifted using a 4-point lift with attachment points located on the stacking bracket. Figure 2-5 shows a sample package with the lifting configurations. The assumed sling angle is 30°. The applied load, Fl = 15,300 lb.

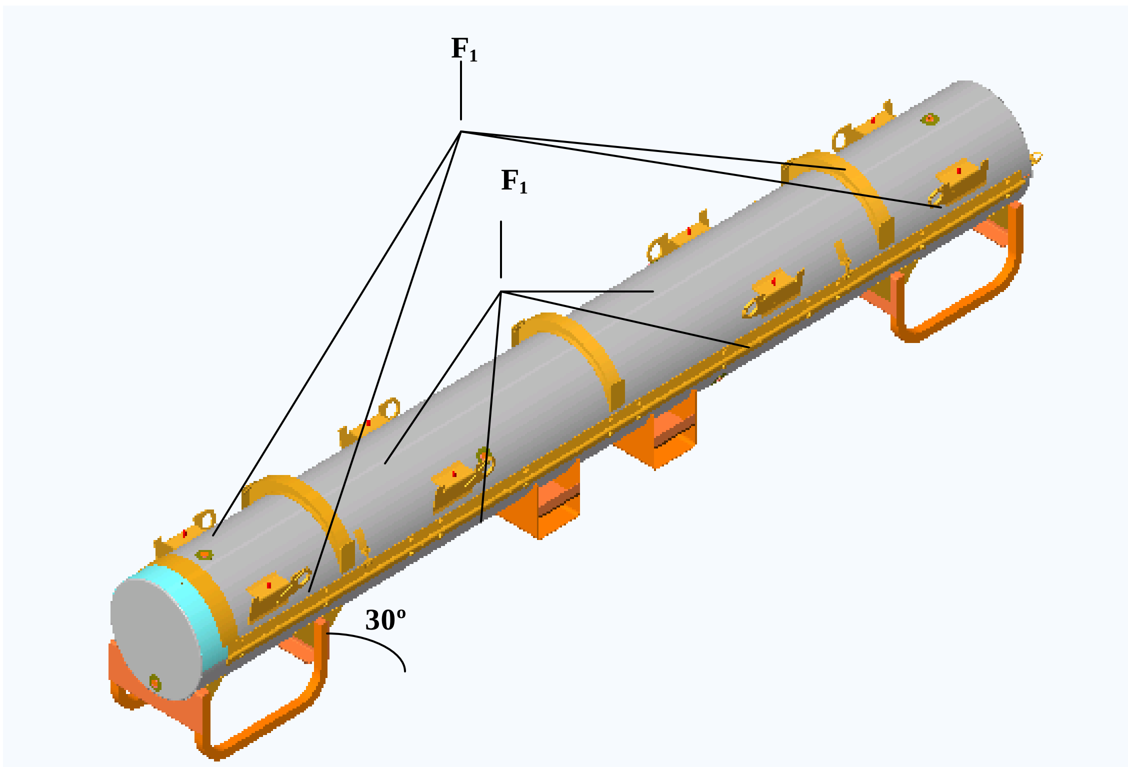

Figure 2-5 Traveller Lifting Configurations

Based on the lifting configuration, the applied load transferred to each lifting hole, F, is:

$$F = \frac{F_l / 4}{\sin 30}$$

$$F = \frac{15{,}300 / 4}{.5} \text{ lb}$$

$$F = 7{,}650 \text{ lb/hole}$$

The applied forces and resultant components for a single lifting hole are shown in Figure 2-6.

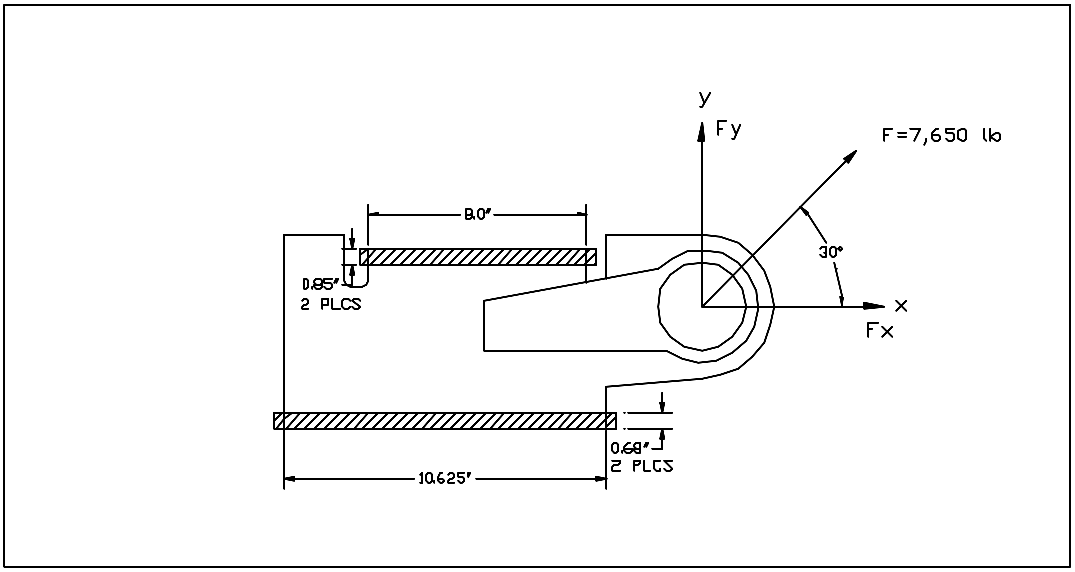

Figure 2-6 Lifting Hole Force Detail

The resulting force components are then:

$$F_x = F(\cos 30)$$

$$F_x = 7650(0.866) \text{ lb}$$

$$F_x = 6{,}625 \text{ lb, and}$$

$$Fy = F(\sin 30)$$

$$Fy = 7650(0.50) \text{ lb}$$

$$Fy = 3{,}825 \text{ lb}$$

The lifting bracket consists of ASTM A276 SS plate with an attached lifting eye. The lifting eye is 0.25" thick ASTM A276 SS plate and is reinforced with a 0.25" plate doubler. A lifting bracket detail is shown in Figure 2-7.

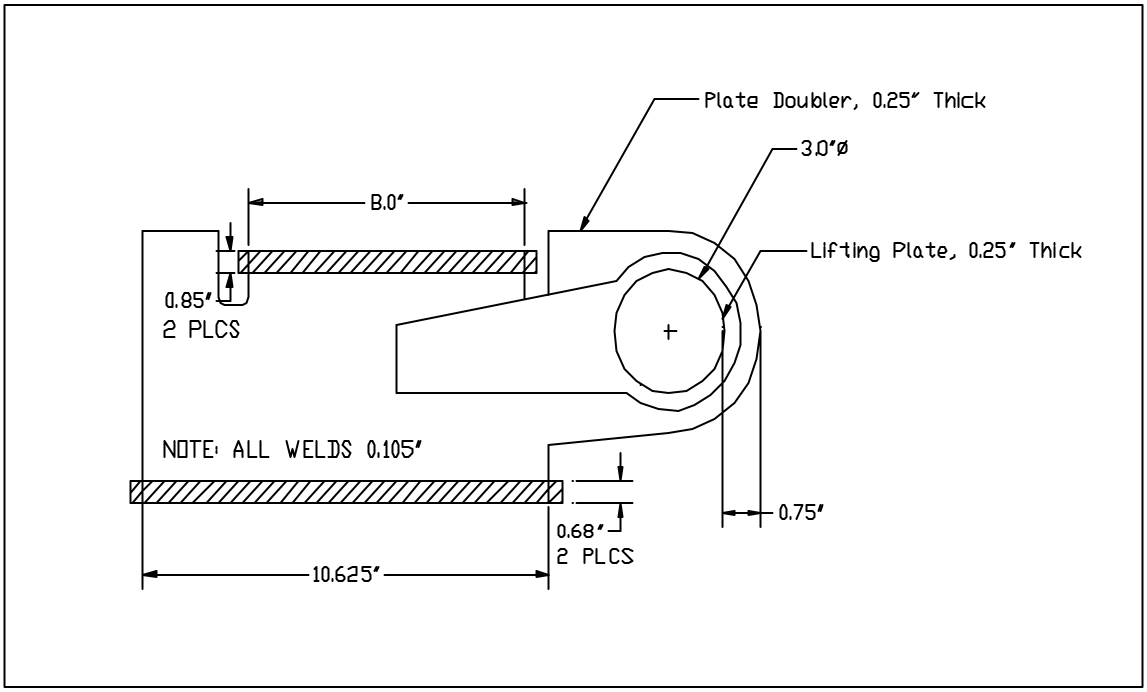

Figure 2-7 Lifting Bracket Fabrication Detail

The lifting analysis consists of two calculations: 1) hole tear-out and, 2) weld strength.

The hole tear-out is assumed to occur at the minimum 0.75" section of material in the lifting eye plate. From Table 2-8, the maximum allowable Shear Yield Stress, τ_y is 18 ksi. The stressed area is the minimum thickness of 0.5" times the section width of the tear out, 0.75" and double shear is assumed. Thus,

$$A = 2(.75)(.5) \text{ in}$$

$$A = 0.75 \text{ in}$$

The elemental volume stress state is described by the Mohr's Circle as shown in Figure 2-8. The resulting stress on the element due to applied load of 7,500 lbs is:

$$s_{x'} = F / A$$

$$s_{x'} = 7650/.75 \text{ psi}$$

$$s_{x'} = 10,200 \text{ psi}$$

The maximum shear stress on the element is then:

$$t_{\max} = \sqrt{\left[\frac{(s_{x'} - s_{y'})}{2}\right]^2 + t_{x'y'}{}^2}$$

$$t_{\max} = \sqrt{\left[\frac{(10{,}200 - 0)}{2}\right]^2 + 0^2}$$

$$t_{\max} = 5{,}100 \text{ psi}$$

Shear tear-out of the hole is not expected since $t_{\max} = 5{,}100$ psi < $t_{allowx} = 18{,}000$ psi.

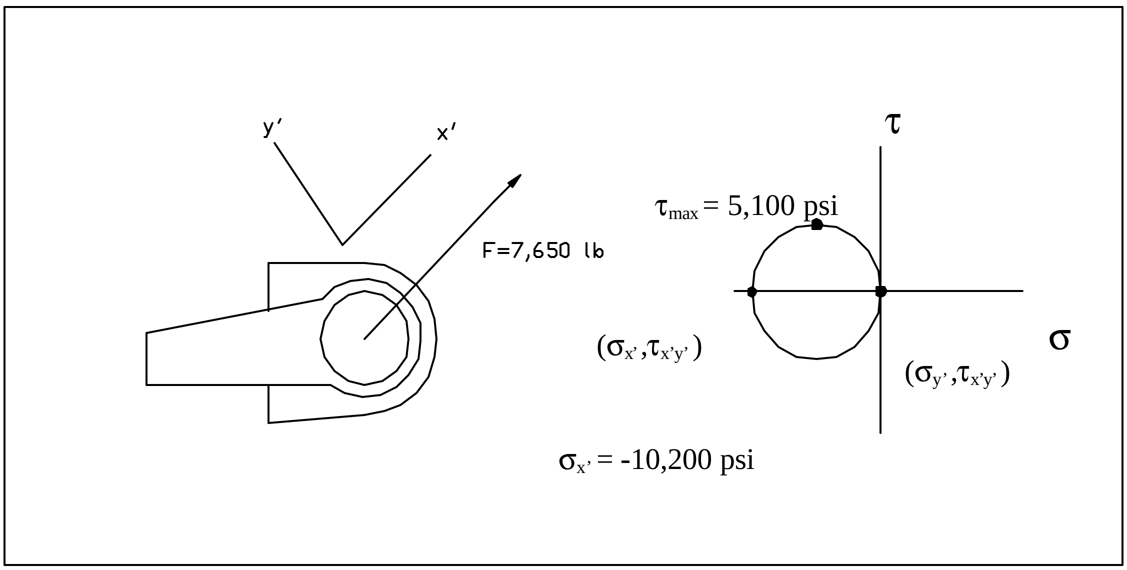

Figure 2-8 Hole Tear-out Model and Mohr's Circle Stress State

The weld attaching the lift plates to the Outerpack shell are required to demonstrate that they are adequate to preclude local weld yielding. The analysis assumes that half of the total welds bear the lifting load. The weld shear stress is found by $t_{weld} = F/A$, where F is the applied vertical or horizontal load and A is the weld area. The assumed weld area is:

$A = hl \sin 45$, where l is (.5)(21.69") = 10.85" from Figure 2-6, and h is the weld thickness, 0.105".

The applied loads are $F_x = 6{,}625$ lbs in the vertical direction and $Fy = 3{,}825$ in the horizontal direction. The weld stresses are then:

$$t_x = F_x / A \text{ and } t_y = F_y / A$$

Substituting values,

$$t_x = 6625 / (.105)(10.85)(.707) \text{ psi}$$

$$t_x = 8{,}225 \text{ psi, and}$$

$$t_y = F_y / A$$

$$t_y = 3825 / (.105)(10.85)(.707) \text{ psi}$$

$$t_y = 4{,}749 \text{ psi}$$

The stresses τ_x and τ_y are perpendicular to each other, and the resulting weld shear stress is:

$$t = \sqrt{\left(t_x^{\,2} + t_y^{\,2}\right)}$$

$$t = \sqrt{\left(8225^2 + 4749^2\right)}$$

$$t = 9{,}498 \text{ psi}$$

The welds are sufficient to prevent local yielding since $t_{\max} = 9{,}498$ psi < $t_{allowx} = 12{,}000$ psi.

Alternative Four Point Lifting – The Traveller package may be lifted using a 4-point lift with attachment points located on the stacking brackets, but with the hinge bolts removed from the top Outerpack. The applied load includes the bottom Outerpack and its contents (the fuel assembly and Clamshell). The bottom Outerpack weighs approximately 1,608 pounds, and the content weight is 2,412 pounds. Thus, the total weight is 4,020 pounds; and using a safety factor of three, the design weight is F_{sb} = 12,060 lb. Therefore, the load per weld is 12,060/4, or 3,015 pounds.

When the top Outerpack hinge bolts are removed, the four swing bolt closure assemblies are loaded in shear. Figure 2-9 shows a sketch of block geometry and weld loading condition.

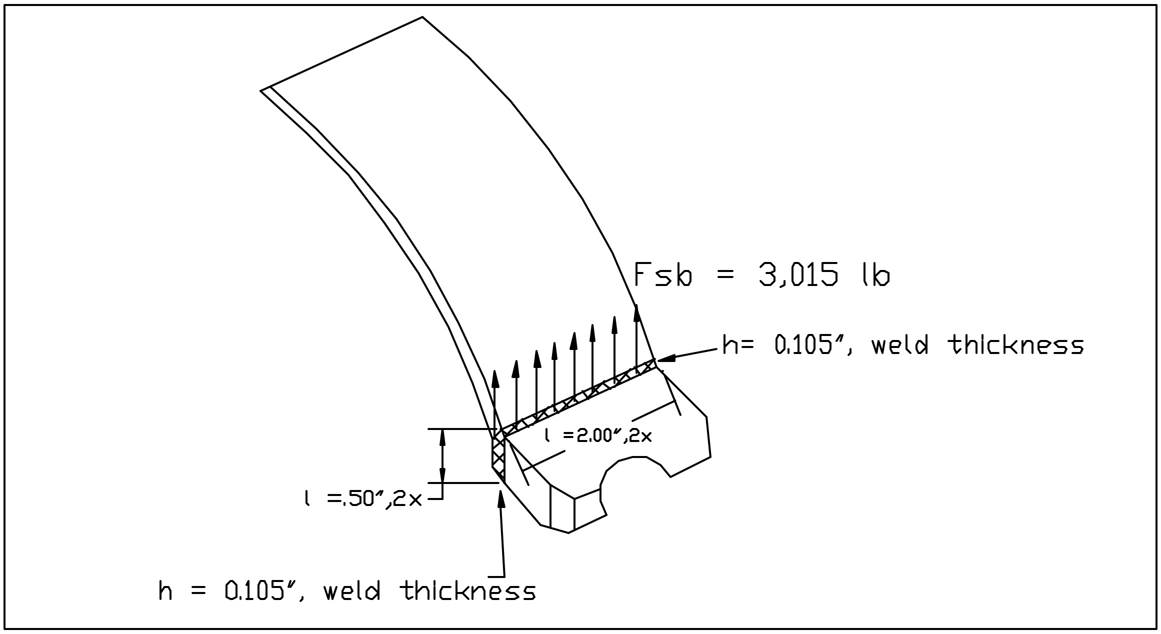

Figure 2-9 Weld Geometry at Swing Bolt Block

The weld shear stress is found by $t_{sb} = F_{sb}/A$, where F_{sb} is the applied load and A is the weld area.

$A = hl \sin 45$, where l is (2)(.5)+(2)(2) = 5.00" from Figure 2-9, and h is the weld thickness, 0.105".

The applied load per weld is $F_{sb} = 3{,}015$ lbs. The weld stresses are then:

$$t_{sb} = F_{sb}/A$$

$$t_{sb} = 3015/(.105)(5.0)(.707) \text{ psi}$$

$$t_{sb} = 8{,}122 \text{ psi},$$

The welds are sufficient to prevent local yielding since $t_{sb} = 8{,}122$ psi < $t_{allowx} = 12{,}000$ psi.

<u>Forklift Analysis</u> – During package lift by a forklift, only the center portion of the package is supported by the forklift. Consequently, the package is subject to a bending load due to the unsupported weight of the package. The Traveller XL package is conservatively modeled as a cantilever beam with the length equal to half of the overall length (L_f = 112.5 in), and the design lifting load distributed over the length of the package (Figure 2-10). The outer shell is the only assumed structure of the package carrying the bending load.

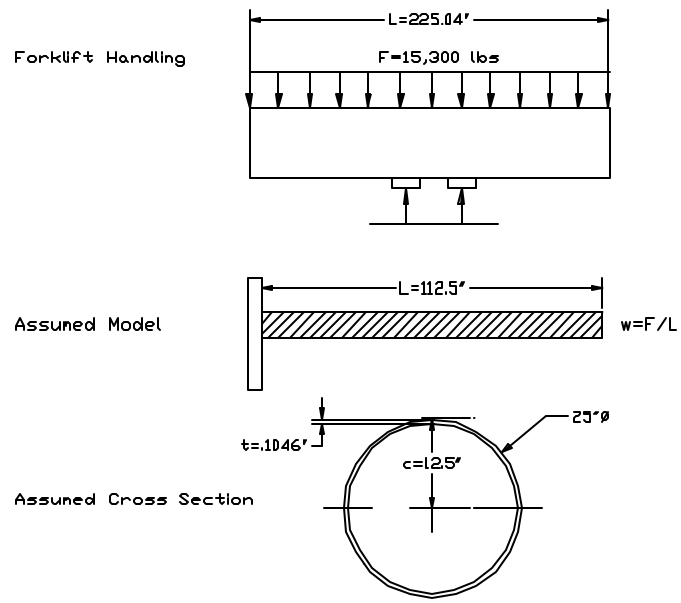

Figure 2-10 Forklift Handling Model and Assumed Cross Section

The bending stress can be determined from the classic flexure equation:

$$s = \frac{Mc}{I}$$, where

c is the distance from the neutral axis to the outer fibers, M is the applied bending moment, and I is the moment of inertia of the section.

The applied moment is given by:

$$M = \frac{wL^2}{2}$$

where w equals F/L from Figure 2-10. The value for w is:

$$w = \frac{F}{L}$$

$$w = \frac{15300}{112.5} \text{ lb/in} = 136 \text{ lb/in}$$

Thus,

$$M = \frac{(136)(112.5)^2}{2} \text{ in-lb}$$

$$M = 860{,}625 \text{ in-lb}$$

The moment of inertia for the shell, I, is calculated as follows:

$$I = \frac{p}{4}(R_o^4 - R_i^4)$$

where R_o=12.5" and R_i=(12.5-.1046)", R_i=12.395".

Thus,

$$I = \frac{p}{4}(12.5^4 - 12.395^4) \text{ in}^4$$

$$I = 634 \text{ in}^4$$

The bending stress is then:

$$s = \frac{(860{,}625)(12.5)}{634} \text{ psi}$$

$$s = 16{,}968 \text{ psi}$$

Forklift loading is not expected to impact the package since $s = 16{,}968$ psi < $s_{yield} = 30{,}000$ psi. As previously noted, the model conservatively assumes the outer shell and the actual Outerpack sandwich structure is would provide even greater margin against bending.

<u>Hoist Ring Analysis</u> – During package lift for fuel loading and unloading, the package is hoisted using the two hoist rings attached to the top end of the Outerpack. The hoist rings attach to the Outerpack using two 3/8-16 UNC socket head cap screws per hoist ring into a welded nut. The four screws are subject to shear loading, combined shear and axial loading, and axial loading. The screws are fabricated to a minimum yield strength of 100,000 psi. The load per bolt is the design lifting load of 15,500 pounds distributed by the four bolts. Thus, the load per bolt is 3,825 pounds. The allowable axial stress is the yield stress of 100,000 psi and the allowable shear stress is 0.6Sy, or 60,000 psi. The stressed area is 0.0775 in^2. The applied stress is then:

$$t = F/A$$

$$t = {}^{3825}\!/_{.0775} \text{ psi}$$

$t = 49{,}355$ psi, which is less than the allowable shear stress of 60,000 psi as well as the axial allowable stress of 100,000 psi and is acceptable.

When the package is vertical, the coupling nut will be subject to a shear load. The nut is 3/8-16 (P=1/16=0.0625) and the material is 18-8 stainless steel. The tolerance gap is 0.0057 inches. The allowable shear stress is 18,000 psi.

The stressed area of the internal thread is found by:

$A = pD_s t_i n$ where D_s is the minimum major diameter 0.3595 inches, t_i is the internal thread thickness (7/8P-2*gap = .0432 inches), and n is the number of stressed threads 16*(21/64) = 5.25.

$$A = p\,(0.3595)(0.0432)(5.25) \text{ in}^2$$

$$A = 0.256 \text{ in}^2$$

The shear stress is then:

$$t = {}^{F}\!/_{A}$$

$$t = {}^{3825}\!/_{.256} \text{ psi}$$

$t = 14{,}941$ psi, which is less than the allowable material shear stress of 18,000 and is acceptable.

2.12.2.2.3 Tie-Down Analysis

The Traveller packages are secured to the transport conveyance by means of strapping across the top of the package(s) and placing a chain inboard from the welded plate at the package legs. Since there are no structural devices designed for tie-down, a tie-down analysis is not required.

2.12.2.2.4 Design Temperature Analysis –40°F (-40°C) and 158°F (70°C)

The materials of construction of the Traveller Outerpack include ASTM A240 Type 304 Stainless Steel for the shells and low density, closed cell polyurethane impact limiter/thermal insulator (10 pcf along the axis, *6 pcf inside the top and lower pillows, and* 20 pcf *between the top and lower pillows*). The Clamshell is comprised of ASTM B209/B221 Type 6005-T5 Aluminum. As demonstrated in the below sections, the package is suitable for transport operations over the required design temperature range.

<u>Brittle Fracture</u> – Aluminum alloys, including 6005-T5 Aluminum, do not exhibit a ductile-to-brittle temperature transition; consequently, neither ASTM nor ASME specifications require low temperature Charpy or Izod tests of aluminum alloys. Thus, brittle fracture of the aluminum components is not expected. Austenitic steels such as 304 Stainless Steel have a Face Centered Cubic (FCC) structure and consequently exhibit a ductile-to-brittle transition at cryogenic temperatures near -297°F (-183°C). Thus, brittle fracture of the stainless steel components is not expected.

<u>Mechanical Properties For Design Temperature Range</u> – The range of tensile and yield strength of 6005 series Aluminum over the design temperature range will not preclude the package from performing its intended design function. Figure 2-11 provides the temperature dependent yield and tensile strengths typical for a 6000-series aluminum up to approximately 212°F (100°C). Furthermore, the recommended operating temperature of aluminum alloys for structural applications is up to a temperature of 400°F (204°C), which is well below the maximum design temperature of 158°F (70°C).

The range of tensile and yield strength of 304 stainless steel over the design temperature range will not preclude the package from performing it intended design function. Figure 2-12 provides the temperature dependent yield and tensile strengths for 304 SS up to approximately 194°F (90°C).

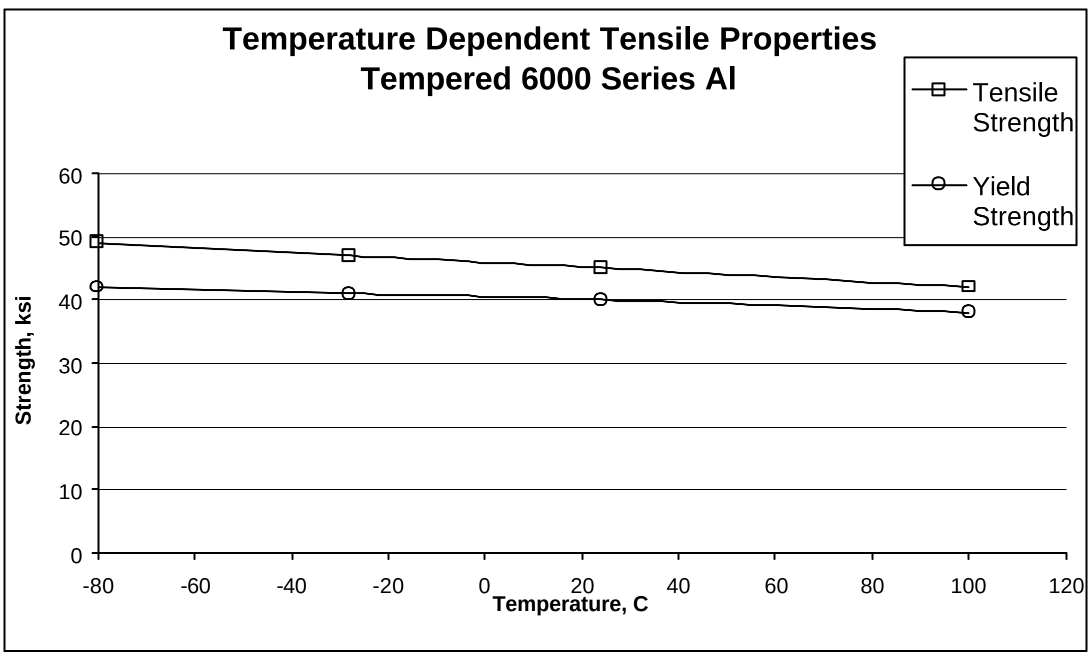

Figure 2-11 Typical Temperature Dependent Tensile Properties for Tempered 6000 Series Al

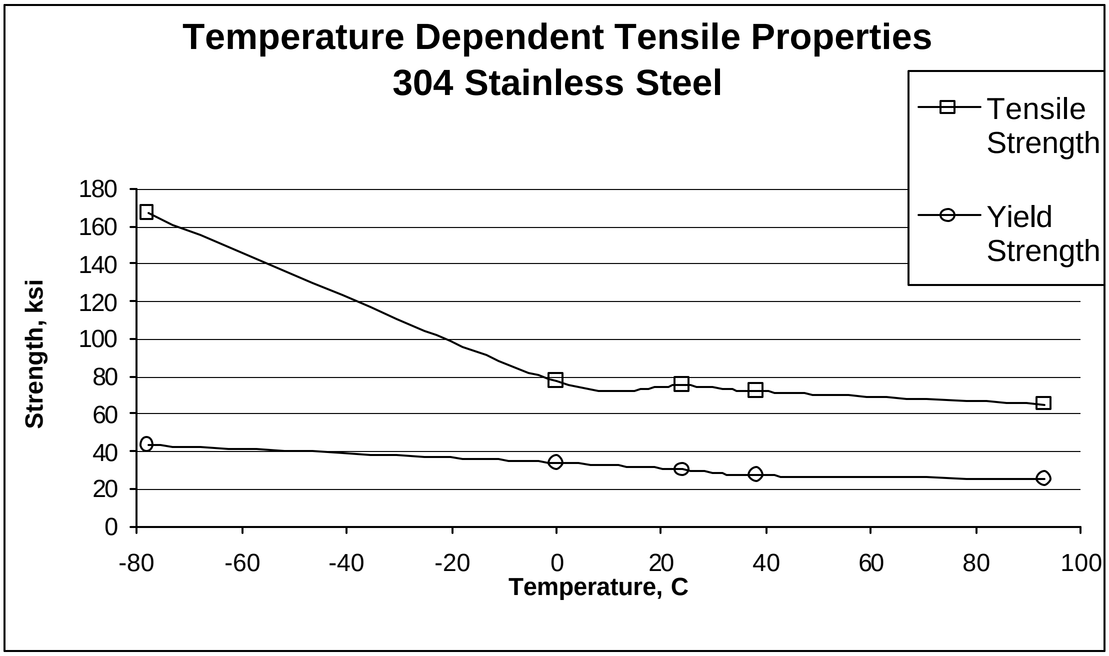

Figure 2-12 Temperature Dependent Tensile Properties for 304 SS

Temperature Evaluation of Foam – The foam is used as a crushable impact limiter and a special thermal insulator. This section only considers the mechanical properties since the thermal functions are evaluated in Section 3, Thermal Evaluation. The foam exhibits a general increase in compressive strength as temperature decreases. Figures 2-13, 14 and 15 show the compressive strength for the 10 pcf (pound per cubic foot), 20 pcf, and 6 pcf foam as a function of temperature, respectively. Of interest is the area under each temperature curve from 0-60% strain (the recommended energy absorption operation range of the foam). For each foam density, the temperature range considered does not significantly impact the energy absorption characteristics. Also, Figures 2-15 show that the compressive strength difference between –29°C and 24°C are relatively similar indicating at -40°C the behavior of the foam will not significantly change. Figure 2-16 provides the temperature dependent strength of each foam density at 10% strain from -54°C to 82°C. The curves show essentially a linear increase in crush strength as temperature decreases. Therefore, the impact properties of the foam are acceptable for use in the temperature range from -40°F (-40°C) to 158°F (70°C).

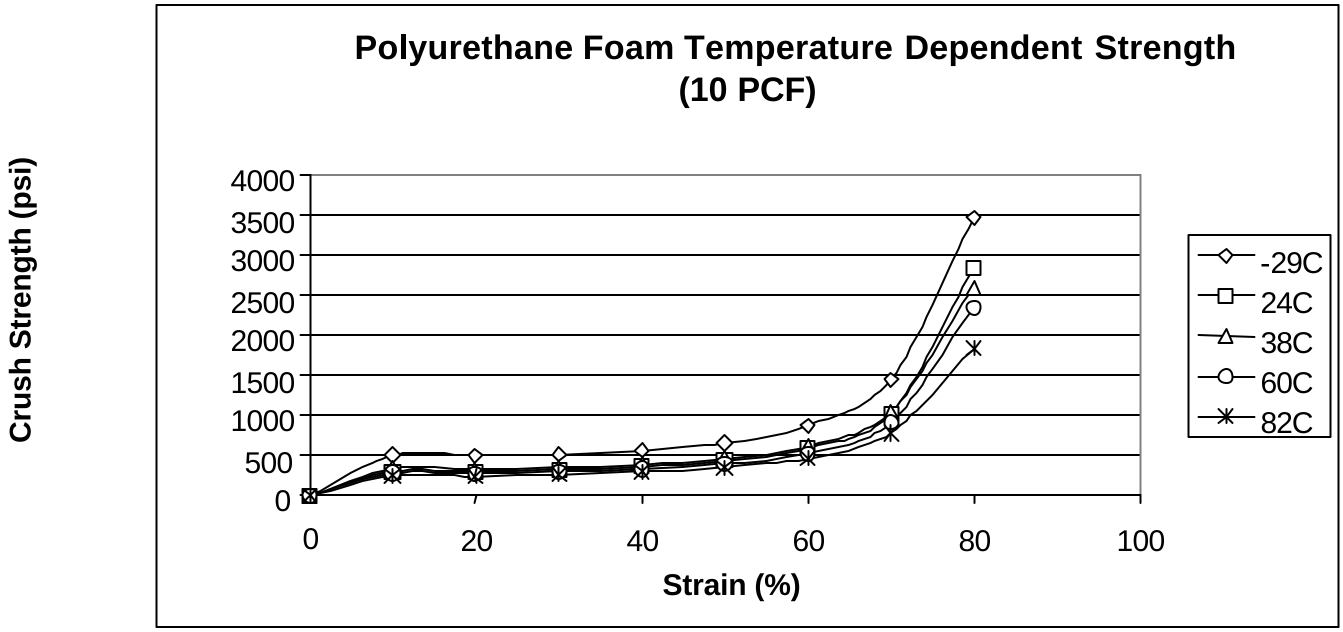

Figure 2-13 Temperature Dependent Crush Strength for 10 PCF Polyurethane Foam

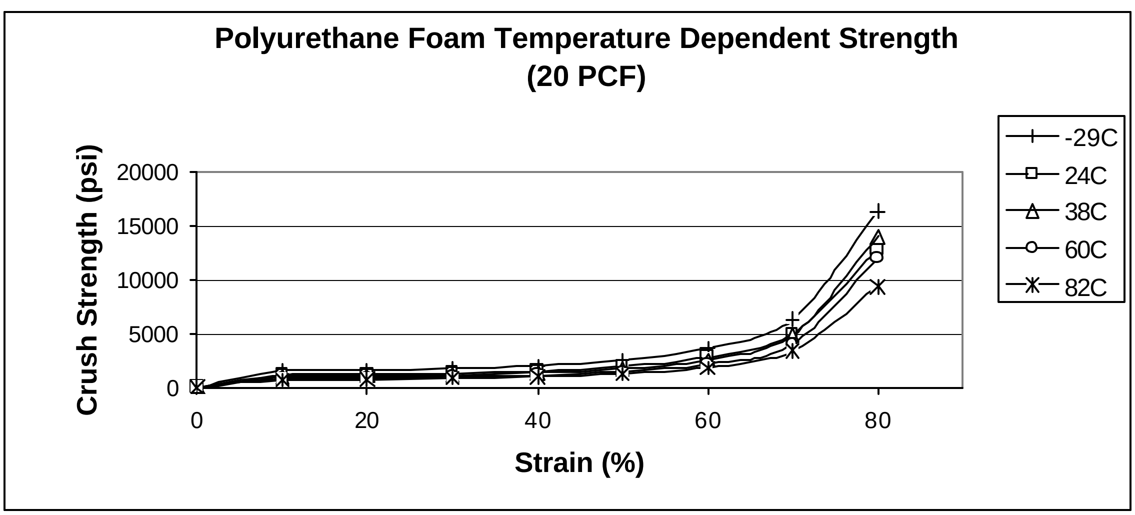

Figure 2-14 Temperature Dependent Crush Strength for 20 PCF Polyurethane Foam

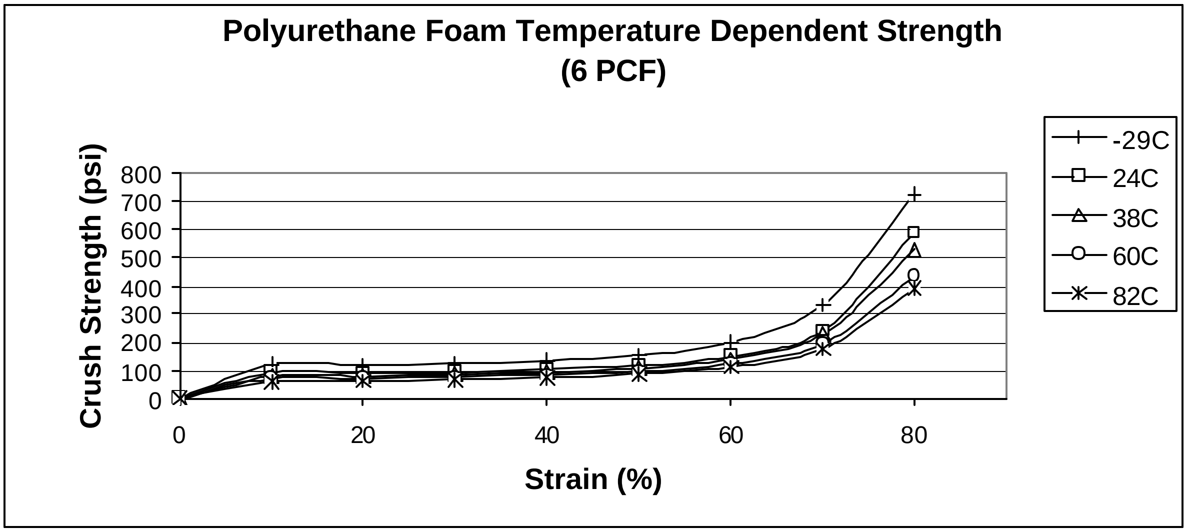

Figure 2-15 Temperature Dependent Crush Strength for 6 PCF Polyurethane Foam

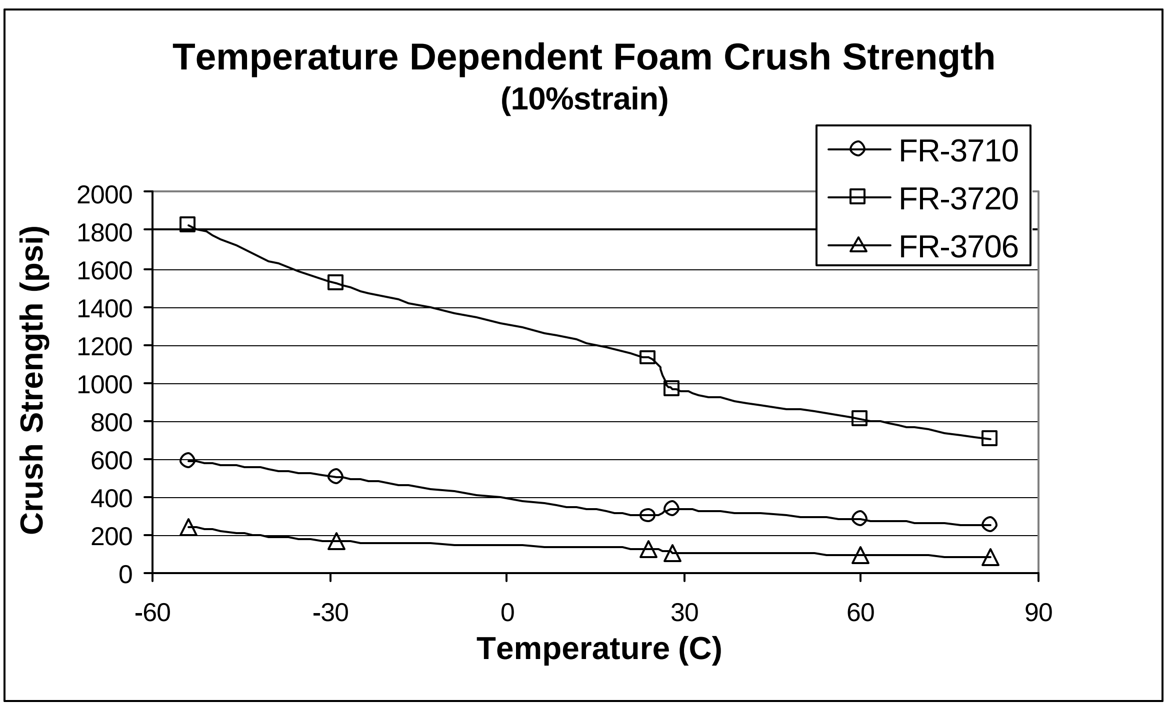

Figure 2-16 Temperature Dependent Crush Strength for Traveller Foam at 10% Strain

Differential Thermal Expansion – Differential thermal expansion (DTE) is expected to only impact the fuel assembly and Clamshell interface. The Outerpack is not under physical constraints and can accommodate thermal growth. Differential thermal expansion between the foam and the stainless steel shells of the Outerpack is easily accommodated by the elastic properties (low modulus value) of the foam.

However, the Ultra-high Molecular Weight (UHMW) polyethylene does have a significantly higher coefficient of thermal expansion (CTE) when compared to 304 stainless steel. For this reason, the moderator panels are segmented along their lengths to accommodate the differential thermal expansion between the polyethylene and the inner stainless steel shells of the Outerpack. Holes in the polyethylene segments are used to attached the panels to the inner Outerpack shells using threaded studs. These studs must not be loaded by the individual panel differential thermal expansion, or contraction. For this reason, each hole drilled into the polyethylene panel is significantly large to preclude thermally induced stresses in the bolt studs. The following calculation addresses this case.

The polyethylene moderator blocks are attached by 0.375 inch diameter weld studs on the inner skin of the on the Outerpack. The weld studs penetrate the moderator blocks through 0.563 inch diameter holes). The blocks are mounted with a nominal gap, block to block, of 0.260 inches. The coefficients of thermal expansions are:

- *304 stainless steel9.6 μ in/in-F*
- *UHMW polyethylene72 – 111 μ in/in-F*

Using the worst difference in expansion coefficients, 100 μ in/in-F, the gaps between the blocks will accommodate heat up from 70° to 167°F. In addition, there is an additional 0.094 inch of clearance between the weld studs and each side of the holes in the polyethylene that will allow blocks with less than nominal clearance to slide in a direction to provide uniform clearance alo ng the length of the Traveller.

Because the polyethylene's coefficient of expansion is much greater than stainless steel, interference between moderator blocks is not an issue when temperature drops. Instead, it is the interference between the blocks and the weld studs. Based on nominal clearances and a maximum distance of 17.0 inches from outboard hole-to-outboard hole, the package temperature can drop from 70°F to -41°F before the polyethylene is stressed. Most of the moderator blocks have significantly smaller distances between the outboard holes (6.5 to 12.5 inches) allowing them to accommodate larger temperature changes.

See Licensing drawings for additional details.

Analyzing the DTE between the fuel assembly and the Clamshell is evaluated assuming fuel loading is performed at 70°F (21°C) and shipped to a cold environment of -40°F (-40°C) since the aluminum will tend to contract more than the fuel assembly. The thermal growth is found by the familiar equation:

$\Delta L = a\,(\Delta T)\,L_o$, where ΔL is the total growth, L_o CS is the original length of the Clamshell (202 inches), $L_{o\ FA}$ is the original length of the fuel assembly (188.86 inches, per drawing 1453E86), ΔT is the temperature change (110°F), and α is the coefficient of thermal expansion.

For Aluminum, α = 13 μin/in-°F. For Zircalloy, α = 2.79 μin/in-°F.

The differential thermal growth between the Clamshell and the fuel assembly is then:

DTE = { $\Delta L = a\,(\Delta T)L_{oCS}$ Al }- { $\Delta L = a\,(\Delta T)L_{oFA}$ Zirlo}

= {13e-6x110x202} inches- {2.79e-6x110x188.86} inches

= 0.29-0.058 inches

Thus,

DTE =0.23 inches (the fuel assembly grows 0.23 inches relative to the Clamshell).

The combined thickness of the base cork rubber and axial clamp cork rubber is 0.50 inches and can accommodate the growth due to differential thermal expansion. Thus, DTE is not a concern. Since the total differential growth associated with the XL Clamshell is greater than the STD Clamshell, it is the bounding calculation.

2.12.2.2.4.1 Internal/External Pressure

The Traveller package utilized acrylic coated fiberglass seals for thermal protection and to preclude dust and other contaminants from entering the package. These seals are not continuous, and do not form an airtight pressure boundary. The package does not maintain a boundary between pressure gradients and is not designed to be pressurized during transport. Thus, internal/external reduced pressure will not impact the structural integrity of the package.

2.12.2.2.4.2 Vibration

The package must be evaluated to consider the effects of normal vibration on the design performance. The isolation system is designed to dampen normally induced vibrations from transport, and is not fundamental to the safe operation of the package. However, the Outerpack must maintain its structural integrity during transport to maintain a safe transport condition. Typical package attachment to a transport conveyance for the Traveller includes nylon straps or chain mounted both over the package and on the gusset tray connected to the support legs pointed inboard. The loading configuration can be modeled as a simply supported beam. Furthermore, the Outerpack is conservatively modeled considering only the outer shell at the first mode of vibration. The typical natural frequency range for transportation vehicles, $f_{nat\ TRANS}$, is 3.7-8 Hz . The natural frequency of the Outerpack can be determined from.

$$f_{natOP} = a\sqrt{(EIg/l^3)/m}$$

where a=1.57 (primary mode coefficient assuming hinge-hinge end conditions for additional conservatism), E=29.4E6 psi, I=634 in^4, m=2633 pounds, g = 386.4 in/s^2 and l=158 in (distance from gusset tray to gusset tray). Substituting values:

$$f_{natOP} = 1.57\sqrt{[(29.4E6)(634)(386.4)/(158)^3]/2633} \quad \text{1/s (Hz)}$$

$$f_{natOP} = 1.57\sqrt{693} \text{ Hz}$$

$$f_{natOP} = 41 \text{ Hz}$$

Since the natural frequency of the Outerpack is greater than the natural frequency typical of a transportation vehicle, resonance of the Outerpack is not expected and normally induced vibrations will not preclude the package from performing its design function.

2.12.2.2.5 Water Spray

The Traveller Outerpack is cylindrical, and shaped so that water will not be collected. Since the shell is fabricated of 304 SS, the water spray will not impact the structural integrity of the package.

2.12.2.2.6 Compression/Stacking test

The Traveller package must demonstrate elastic stability for a 5 g static load. No credit is taken for the circumferential stiffeners or the forklift support tubes. The analysis assumes the stacking load is uniformly distributed over the four outermost stacking brackets on the Outerpack. Figure 2-17 depicts the shell compression/stacking model.

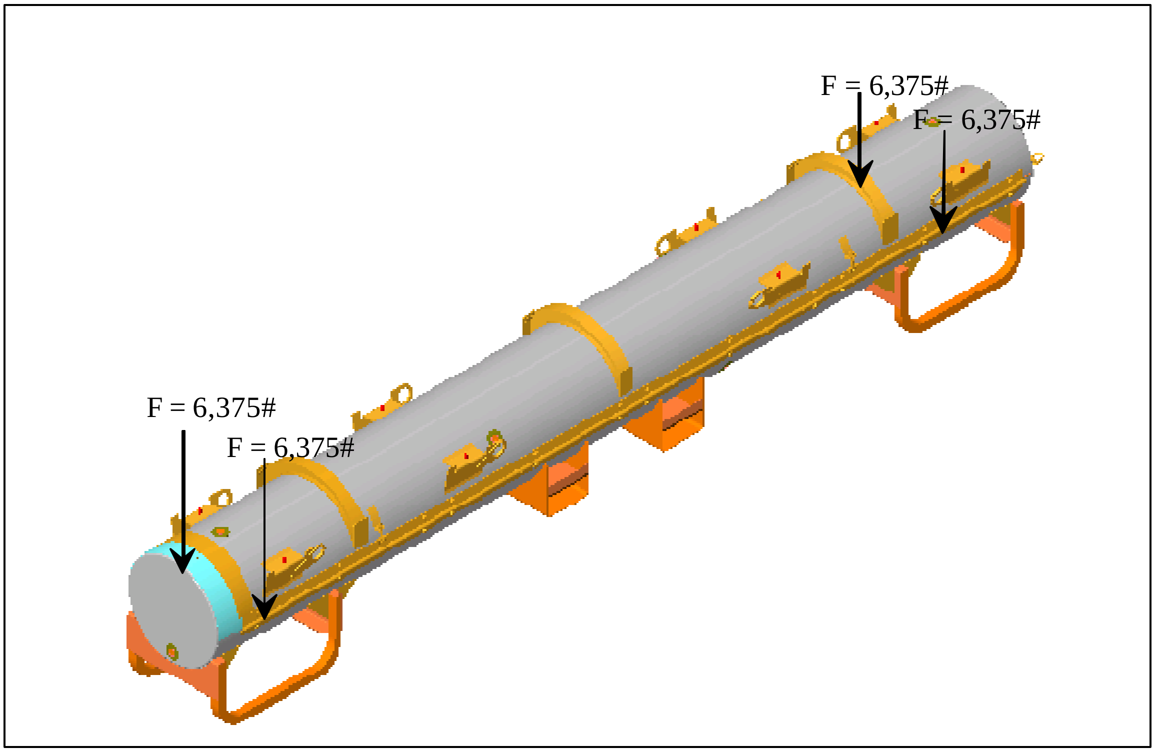

Figure 2-17 Compression/Stacking Requirement Analysis Model

The applied stacking force for the stacking test was determined to be:

$Fs = 25{,}500$ lb from Section 2.12.2.

The load path is assumed to follow through the welds of the stacking brackets, through the Outerpack side, and then to the leg supports. This assumption is based on the package stacking configuration or the placement of weight on the package top. Each loaded section will be analyzed for its structural integrity.

Stacking Bracket – The stacking bracket is expected to experience a shear load on the weld during stacking. The loading configuration for a single bracket is shown in Figure 2-18.

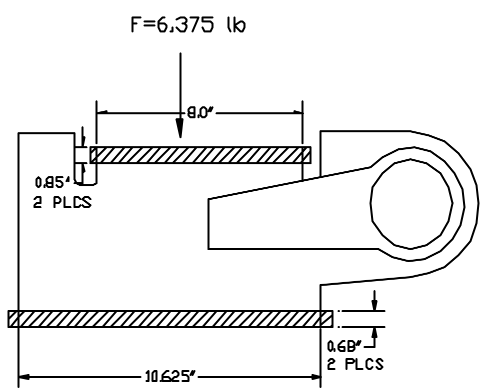

Figure 2-18 Stacking Force Model on Stacking Bracket

The load on each stacking bracket is found by dividing the applied load of 25,500 pounds by the four brackets that support the load:

$$F = 25{,}500/4 \text{ lb}$$

$$F = 6{,}375 \text{ lb}$$

The weld shear stress is found by $t_{weld} = F/A$, where F is the applied vertical or horizontal load and A is the weld area. The assumed weld area is the total weld area of each bracket and is found by:

$A = hl \sin 45$, where l is 21.69", and h is the weld thickness, 0.105".

The weld stress is then:

$$t = F/A$$

Substituting values,

$$t = 6375/(.105)(21.69)(.707) \text{ psi}$$

$t = 3{,}959$ psi, which is less the allowable weld shear stress of 12 ksi.

2.12.2.2.6.1 Outerpack Section

The stacking bracket is expected to experience a compressive load through the package side cross section during stacking as the force follows the projected load path The loading configuration and model for the Outerpack section is shown in Figure 2-19.

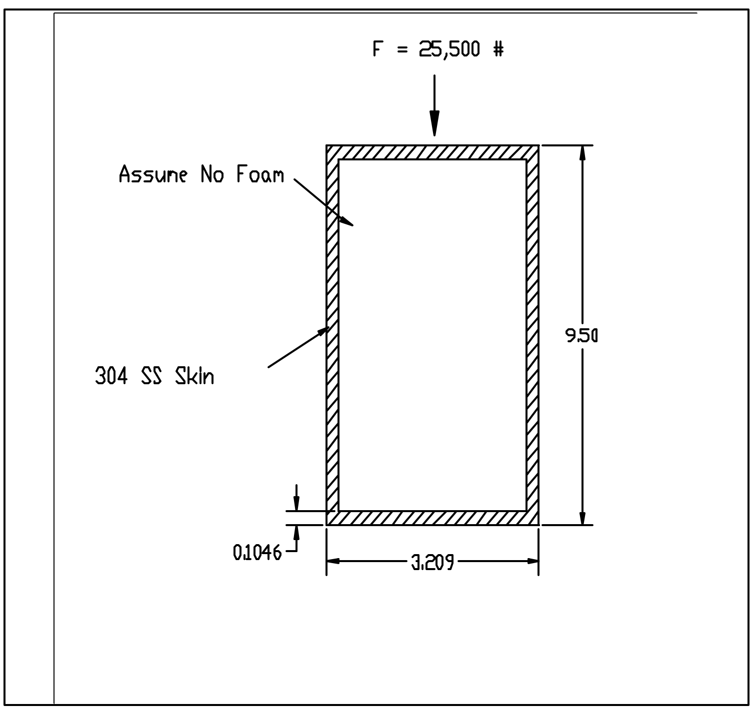

Figure 2-19 Outerpack Section Compression Model

The evaluation first examined the slenderness ratio of this section to determine if buckling is applicable. The model conservatively assumed no structural credit for the foam. In addition, the model assumed the force path section is from the base of the stacking bracket to the top of the support leg. The cross section consisted of a rectangular section of dimensions 9.50" x 3.209" with a wall thickness of 0.1046". The critical buckling load will be calculated and compared to the actual load to determine elastic stability of the Outerpack section.

The slenderness ratio, SR, can be expressed as:

$$SR = l / k$$

where l is the effective length, 9.50 inches, and the radius of gyration, k, is:

$$k = \sqrt{I/A}$$

For the Outerpack section, the moment of inertia, I, and the cross section area, A are:

$$I = \left(wl^3 - w_i l^3{}_i\right)/12 \text{ in}^4$$

$$I = \left(3.209\{9.50\}^3 - 3.0\{9.29\}^3\right)/12 \text{ in}^4$$

$$I = 28.8 \text{ in}^4$$

$$A = wl - w_i l_i \text{ in}^2$$

$$A = (3.209\{9.50\} - 3.0\{9.29\}) \text{ in}^2$$

$$A = 2.62 \text{ in}^2$$

Thus, the value for k is:

$$k = \sqrt{28.8/2.62} \text{ in}$$

$$k = 3.32 \text{ in}$$

The corresponding slenderness ratio is then:

$$SR = 9.50 / 3.32 \text{ in/in}$$

$$SR = 2.86$$

The limiting slenderness ratios for columns are as follows:

<u>Long Columns</u>

$\left(l/k\right)_1 = \sqrt{\dfrac{2\pi^2 CE}{\sigma_y}}$ where the end condition C is conservatively assumed to be unity, E is Young's Modulus, and σ_y is the tensile yie ld stress.

Substituting values:

$$\left(l/k\right)_1 = \sqrt{\frac{2\pi^2(29.4E6)}{30000}}$$

$$\left(l/k\right)_1 = 139$$

<u>Short Columns</u>

$$\left(l/k\right)_2 = .282\sqrt{\frac{Al^2}{\pi^2 I}}$$

Substituting values:

$$\left(l/k\right)_2 = .282\sqrt{\frac{2.62(9.50)^2}{\pi^2 28.8}}$$

$$\left(l/k\right)_2 = .257$$

Thus, .257< 2.86 (SR) < 139 and the Outerpack section is conside red an intermediate column. The critical load for this column is given by:

$$P_{cr} = A(\sigma_y - \left\{\frac{\sigma_y}{2\pi}\frac{l}{k}\right\}^2 \frac{1}{CE})$$

$$P_{cr} = 2.62(30000 - \left\{\frac{30000}{2\pi}\frac{9.50}{3.32}\right\}^2 \frac{1}{29.4E6})$$

$$P_{cr} = 78{,}583 \text{ lb}$$

Since the actual load of 25,500 pounds is less than the critical buckling load of 78,583 pounds, the Outerpack section is considered stable during compression from stacking.

2.12.2.2.6.2 Leg Support

The leg support is expected to experience a compressive load through the straight top cross section during stacking as the force follows the projected load path The loading configuration and model for the leg support section is shown in Figure 2-20. There are eight (8) leg sections of 2"x2"x.120" 304 SS tubing of approximately 10" length, The expected load for each leg section is 25,500/8 pounds, or 3,188 pounds.

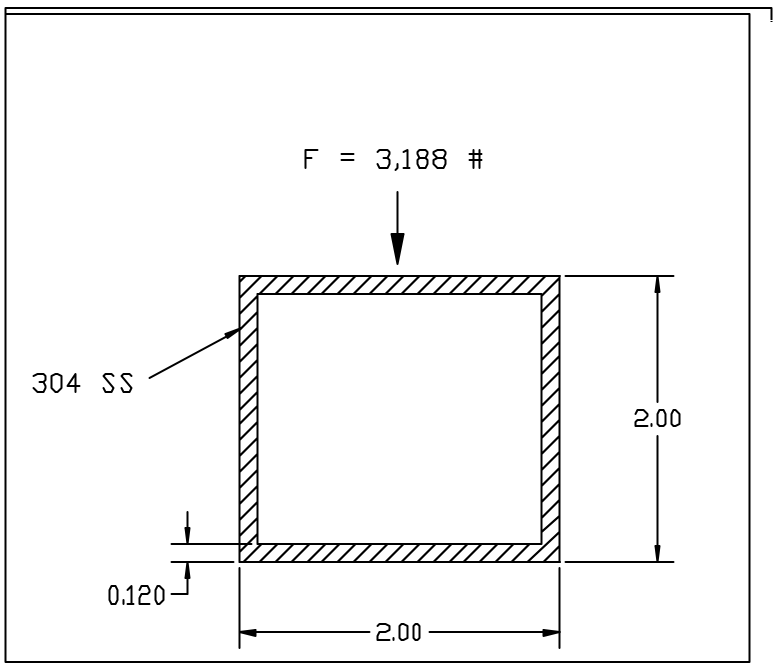

Figure 2-20 Leg Support Section Compression Model

The evaluation will first consider the slenderness ratio of this section to determine if buckling is applicable. The critical buckling load will be calculated and compared to the actual load to determine elastic stability of the leg support section.

The slenderness ratio, SR, is:

$$SR = l / k$$

where l is the effective length, 10.0 inches, and the radius of gyration, k, is:

$$k = \sqrt{I / A}$$

For the Outerpack section, the moment of inertia, I, and the cross section area, A are:

$$I = \left(wl^3 - w_i l^3{}_i\right)/12 \text{ in}^4$$

$$I = \left(2.0\{2.0\}^3 - 1.76\{1.76\}^3\right)/12 \text{ in}^4$$

$$I = 0.533 \text{ in}^4$$

$$A = wl - w_i l_i \text{ in}^2$$

$$A = \left(2.0\{2.0\} - 1.76\{1.76\}\right) \text{ in}^2$$

$$A = 0.902 \text{ in}^2$$

Thus, the value for k is:

$$k = \sqrt{0.533/0.902} \text{ in}$$

$$k = 0.769 \text{ in}$$

The corresponding slenderness ratio is then:

$$SR = 10.0/.769 \text{ in/in}$$

$$SR = 13$$

The limiting slenderness ratios for columns is:

Long Columns

$\left(l/k\right)_1 = \sqrt{\dfrac{2p^2 CE}{s_y}}$ where the end condition C is conservatively assumed to be unity, E is Young's Modulus, and σ_y is the tensile yield stress.

Substituting values:

$$\left(l/k\right)_1 = \sqrt{\frac{2p^2(29.4E6)}{30000}}$$

$$\left(l/k\right)_1 = 139$$

<u>Short Columns</u>

$$\left(l/k\right)_2 = .282\sqrt{\frac{Al^2}{p^2 I}}$$

Substituting values:

$$\left(l/k\right)_2 = .282\sqrt{\frac{0.902(10.0)^2}{p^2 0.534}}$$

$$\left(l/k\right)_2 = 1.16$$

Thus, 1.16< 13 (SR) < 139 and the leg support section is considered an intermediate column. The critical load for this column is:

$$P_{cr} = A(s_y - \left\{\frac{s_y}{2p}\frac{1}{k}\right\}^2 \frac{1}{CE})$$

$$P_{cr} = 0.902(30000 - \left\{\frac{30000}{2p}\frac{10.0}{0.77}\right\}^2 \frac{1}{29.4E6})$$

$$P_{cr} = 26{,}942 \text{ lb}$$

Since the actual load of 3,188 pounds is less than the critical buckling load of 26,942 pounds, the leg support section is considered stable during compression from stacking.

2.12.2.2.7 Penetration

The penetration test can be characterized as a localized impact event on the outer skin of the Outerpack. The energy imparted onto the outer skin is equal to the potential energy of the falling pin:

$PE = mgh$, where the mass of the pin is 13 lb and the drop height is 40 inches. To obtain correct units of energy, the gravitational constant g_c must be used in the energy equation. Thus,

$$PE_{penetration} = \frac{(13)(40)(32.2)}{32.2} \text{ in-lb (ft*s2)/ft*s2}$$

$$PE_{penetration} = 520 \text{ in-lb.}$$

By comparison, the energy locally imparted to the outer skin from the pin-puncture drop test is determined from the dropped package mass and the drop height. The mass of the package is 5,100 lb, and the drop height is 40 inches. Thus,

$$PE_{pin} = {mgh}/{g_c} = mh$$

$$PE_{pin} = (5100)(40) \text{ in-lb.}$$

$$PE_{pin} = 204{,}000 \text{ in-lb.}$$

Pin puncture drop tests have demonstrated that the outer skin was not perforated as a result of impact onto the pin. Since the impact energy of the pin puncture drop test is approximately 400 times greater than that of the pin penetration, the pin puncture drop test bounds the pin penetration. Thus, the pin penetration impact is not expected to result in any significant structural damage to the Outerpack.

2.12.2.2.8 Immersion Analysis

The Traveller package uses acrylic fiberglass seals for thermal protection and to preclude dust and other contaminants from entering the package. The seals are not continuous around the perimeter of the package and do not form a pressure boundary. In the event of water submersion, the inner portion of the package will fill with water creating equal hydrostatic pressure on the Outerpack and Clamshell surfaces. This condition would not result in a stress gradient through the Outerpack or Clamshell. Thus, immersion will not impact the structural integrity of the package.