Section 1.0

General Information

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Abbreviations Used in this Section

CDC	Centers for Disease Control
Co-60	Cobalt-60, a radioactive isotope
Cs-137	Cesium-137, a radioactive isotope
CoC	Certificate of Compliance
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
HAC	Hypothetical Accident Conditions
NIH	National Institutes of Health
NNSA	National Nuclear Security Administration
NCT	Normal Conditions of Transport

1.0 GENERAL INFORMATION

Throughout the forty-five year plus business history of J.L. Shepherd & Associates, the delivery and recovery of Type B quantities of radioactive materials has occurred using, predominantly, the 20 WC series, Department of Transportation (DOT) specification package. This package design allows JLS&A to market a variety of devices containing Type B quantities of imbedded sealed sources, in Special Form, transported in U.S. Department of Transportation Specification 7A Shielded Containers, in a multitude of sizes and configurations. The company, then and now, also manufactures larger irradiators requiring heavier source loading which resulted in the development of Certificate of Compliance Packages (CoC), CoC numbers 5984 and 6208. Both of these CoC packages were voluntarily retired by the company in 2007.

On October 1, 2008 new regulations for the transportation of radioactive materials were implemented. No longer could the currently authorized 20 WC series Department of Transportation packages be used without a Special Permit issued by the Department of Transportation. As a consequence, a replacement package must be developed which meets:

- The needs of the United States Department of Energy, the United States Department of Defense, the National Nuclear Security Administration (NNSA), National Laboratories such as the Centers for Disease Control and National Institutes of Health; the Los Alamos National Labs Off-Site Recovery Program, the United States Department of Homeland Security, Universities, Medical and Pharmaceutical Research Institutions, Blood Banks, and Private Industry to ship hundreds of existing devices which contain Type B quantities of imbedded Cs-137 and Co-60 sources for which no alternate Type B packages are available for re-location, decommissioning or re-loading.

- The needs of many of the above to have replacement Co-60 sources in quantities ranging from 6,500 to 9,000 Curies each shipped and installed in existing irradiators in combined quantities ranging from 19,500 to 29250 Curies, especially for Homeland Security applications and for testing of components used by the Department of Defense, CIA and Commercial, extra-terrestrial (satellite) applications, and the National Institutes of Health and Centers for Disease Control.

- The needs of the above to have new/replacement irradiators shipped/installed to meet National Security, Medical Research and Blood Product irradiation requirements and for decommissioning of these devices.

This application describes a package designed to meet the above identified needs. The proposed package utilizes a single Shielded Liner concept. Supplemental applications will include liners of different configuration with maximum dimensions and weights. All Shielded Liner configurations will be as evidenced by demonstrative computer modeling tests conducted by persons and organizations independent of the design and fabrication organizations.

This new Category III package consists of a stainless steel inner and outer shell assembly, augmented by rigidly attached impact limiters affixed to each end. Kaolite 1600, a thermal barrier material, is added to the annular area between the inner and outer shell walls. When loaded, the package presents at a maximum gross weight of 12,500 pounds. The package with proper shielding is capable of transporting radioactivity with a decay output of approximately 450 watts.

1.1 Introduction

The proposed package is identified as the J.L. Shepherd & Associates Model BU650B Radioactive Materials Package, which meets the NRC's requirements for a "B(U)" designation. It is intended for transportation of Type B quantities of radioactive materials as Sealed Sources, in Special Form. This package is not intended for the transportation of fissile materials. Consequently, there is no Criticality Safety Index assigned.

The intended purpose of this application is to allow for use of a Shielded Liner, similar to other, previously licensed, CoC Packages such as the CNS 113 and 114 series packages, NUKEM 10 series packages; Specification 20 WC5 and 20 WC6 DOT packages, which were permitted under 49 CFR 178.362. The principle difference between these packages and the J.L. Shepherd & Associates Model BU650B is that the shielded liners used within the BU650B package are constructed using like materials and methods and are computer modeled in each extreme configuration, under hypothetical accident conditions at their extreme mass. Variations of inner shielded liners are proposed in lesser mass only, thereby enhancing safety as mass decreases.

For an excess of forty years the DOT specification packages served the device manufacturing industry well. These DOT specification 20WC packages provided ease of use, flexibility of loading, simple maintenance processes, and a unique capability of accepting multiple inner packages (lead contained in fully welded steel enclosures) which provided both the radiological shielding necessary and security of the sealed source(s) retained in various confinements therein.

Expanding upon that same principle, J.L. Shepherd & Associates herein presents a shielded liner design which requires minimum material and construction standard for all sizes, not to exceed a maximum size of 6,500 pounds in any configuration. This will allow a shipment of the modeled Shielded Liner at maximum weight, with maximum decay heat at the safety levels achieved during required testing, and under lesser loads of mass and decay heat output, even greater safety levels than those documented. All proposed shielded liners will be modeled in the same manner: the largest most extreme configuration, thereby assuring that like configurations of lesser mass, constructed utilizing the same materials and methods of construction, will continue to provide improved safety during transportation.

1.2 Package Description

1.2.1 Packaging

The general BU650B package description is as follows:

- Maximum weight when fully loaded ~ 12,500 pounds
- Height: ~ 90"
- Diameter: With Impact Limiter ~ 69"; Without ~ 44.5"
- Tare Weight: ~ 5,800 pounds
- Containment: Containment is achieved through limitation to shipment of "Sealed Sources" contents in Special Form.
- Personnel Barriers: None required. The package, as designed and configured does not emit sufficient heat to require personnel barriers.
- Shielding: Shielding is achieved through use of shielded liners, having various sizes necessary to achieve a complete package emitted radiation level of ≤ 0.10 milli-Sieverts at one meter, Normal Conditions of Transport (NCT) and 10 milli-Sieverts at one meter Hypothetical Accident Conditions (HAC).
- Criticality control features: None. This package is intended for the transport of sealed sources in special form and does not have the capability of transporting fissile source material, radioactive materials that are thermally sensitive, radioactive liquids, or gasses.
- Structural Features: The BU650B package sits upon a specially designed, nesting pallet which is used for lifting purposes. For flatbed shipment, tie-down is achieved through use of a "Spider Frame Assembly" that registers atop the package and provides four chain points for securing

the package to a conveyance. Additionally, there are four chain points on the nesting pallet which also secure the pallet to the conveyance. Due to the capability of transport by covered conveyance, a tie-down mechanism is not a functional part of the package, as the package can be safely blocked, utilizing blocking bars, into a covered van or trailer.

Attached to the Outer Shell are impact limiters which are positioned on the top and bottom of the package. These impact limiters are constructed of foam having a 12 pounds (+/-15%) per cubic foot density, encased by a reinforced, welded stainless steel assembly. There are ventilation holes (3 each) on the top of the impact limiter to provide for intumescence of the polyurethane foam during thermal episodes. These ventilation holes are plugged with 2" plastic plugs which will begin to melt away at or slightly before 800°F.

Internal shielded liners are restrained from movement within the package at the lowest point practical by a metal frame assembly constructed of carbon steel, specifically designed for the particular shielded liner in use, to crib or securely hold the shielded liner in event of impact.

The package is closed by the installation of twenty four, ¾"-10UNC grade 316 stainless steel bolts, passing through a flange at the top. The lid and closure assembly is protected by the top Impact Limiter Assembly.

- Heat Transfer Systems: None. The package is limited to a thermal output of 450 watts and therefore does not require active heat transfer mechanisms.

- Package Markings: The package is identified by stencil markings, labels, or signs, which provide for identification of the owner, the Certificate of Compliance Number, and metal trefoil label depicting the international symbol for radioactivity. Also stenciled to the package is the TARE Weight of the package and a Gross Weight Limitation, per 49 CFR Subpart D requirements. All labeling will be in accordance with 49 CFR Subpart E.

1.2.2 Contents

The contents of the BU650B package and Shielded Liners is restricted to sealed sources which have been certified as "Special Form" in accordance with 10 CFR 71.75 and 49 CFR 173.469.

Isotopes to be shipped are less than or equal to 29,250 Curies (450 watts) Co-60; or less than 30,000 Curies Cs-137. Isotopes may be comingled but not exceed 450 watts and are to be loaded into the package dry.

The BU650B package is not designed for transportation of fissile materials, neutron sources, or "Normal Form" radioactivity.

Co-60 and Cs-137 are encapsulated in double stainless steel capsules sealed by weld. There is no moisture content or moderator.

Sources are mounted in metal (aluminum or stainless steel) racks/spiders/cages located in the cavity of the Shielded Liner.

There are no non-fissile absorbers or moderators.

There is no material subject to chemical, galvanic, or other reactions, including the generation of gasses contained within the Shielded Liner or complete package assembly.

The maximum radioactive payload is 25 pounds.

The maximum decay heat is 450watts.

Loading Restrictions. All Co-60 and Cs-137 sources loaded must have current leak test certificates and be certified to meet the Special Form requirement (tests) of 10 CFR 71.75 and 49 CFR 173.469.

Sources intended to be transported, if found to be in "normal" form or leaking will be encapsulated and sealed by currently approved process, and then certificated as "Special Form" prior to loading for shipment, in accordance with 49 CFR 173.469; and 10 CFR 71.75, as appropriate.

The capsules, or radioactive contents, transported within a shielded liner may vary in size, (but never exceed the maximum package payload) due to radioactive output of sources and nest within cavity of the inner shielded liner. The shielded liner is retained within the inner package by use of a rigid steel framing sufficient to prevent movement during extreme events.

Neutron absorbers are not present in this package. The BU650B, as designed, is not intended for the transport of neutron emitters.

There are no gasses found within the radioactive contents proposed as both isotopes are inert chemical solids held by sealed containment.

The maximum weight of package contents (i.e., payload) ,which includes the shielded liner at 6,500 pounds and shoring of 200 pounds or less. is 6,700 pounds.

As designed, the maximum decay heat capability of the package is 450 watts (29,250 Curies of Co-60). (Cs-137 to be held to less than 30,000 curies).

Loading and unloading of the package is as defined in Package Handling and Maintenance Instructions. (See Section 7, Package Operations). Appropriate pre-shipment inspection determinations are also included in those instructions.

Containment is achieved through use of "sealed sources" in "special form" only. Typical sealed sources are encapsulations, sealed by a weld closure, which can be opened only by destroying the sealed source capsule (RegGuide 7.9, paragraph 2.10). Sealed sources are typically leak tested in accordance with ANSI 14.5 or equivalent standards at time of manufacture, and then subsequently by license to possess at specific intervals. In cases where verification of the sealed source is absent or in instances where the method of encapsulation may be found to be leaking, the source will be re-encapsulated in accordance with 49 CFR 173.469 and 10 CFR 71.75, as appropriate, in order to assure a certified "sealed source".

Sealed sources come in a variety of lengths and diameters. Their location within shielded liners is determined by their physical size and output. Sealed sources may be retained in "spiders", cages, or Bailer cans located within the cavity of the shielded liner. This allows for multiple sources to be loaded into one package, provided the maximum gross weight, thermal output, and exposure restrictions are not exceeded.

In all cases, sealed sources are leak-tested at time of manufacture, and at regular intervals in accordance with the license issued to the sealed source owner. Leak tests are verified prior to shipment.

1.2.3. Special Requirements for Plutonium

This package is not intended for the transportation of plutonium and therefore does not have specific plutonium requirements. Therefore, this section is not applicable or considered.

1.2.4 Operational Features

The BU650B package, as designed, does not incorporate special operational features, such as cooling systems, valves, piping, multiple seals, or containment boundaries. Therefore these items are not addressed.

Operation of the package is achieved by following a simple set of opening and closing instructions which consists of a series of steps designed to remove two layers: 1. The Upper Impact Limiter Assembly which requires removal of four pins and clips; and, 2. The Lid/Closure Assembly which is held to the package by 24 each, ¾"-10UNC, grade 316 stainless steel bolts.

For security purposes, a tamper-proof seal is affixed to each shipment at the closure. Any attempt to remove the seal results in an obvious visual indication. These seals are serialized. Each number is recorded on shipping documents in order to avoid "replacement" of a broken seal during transport. Package operating instructions advise those handling packages to contact JLS&A in the event of a missing seal or damaged seal prior to opening the package or conducting any further package handling operations.

1.3 Appendix

1.3.1 References

[1.1] Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, U.S. Nuclear Regulatory Commission, June 1991.

[1.2] NUREG/CR-5502, *Engineering Drawings for 10 CFR Part 71 Package Approvals*, U.S.Nuclear Regulatory Commission, May 1998.

[1.3] Regulatory Guide 7.9, *STANDARD FORMAT AND CONTENT OF PART 71 APPLICATIONS FOR APPROVAL OF PACKAGES FOR RADIOACTIVE MATERIAL,* Revision 2, March 2005.

1.3.2 Drawings

See Drawing List Attached

Section 2

Structural Evaluation

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Common Abbreviations Used in This Section

ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BPVC	Boiler and Pressure Vessel Code
CFR	Code of Federal Regulations
CMS	Computer Modeling Software
D.M.	Design Margin
DOT	United States Department of Transportation
HAC	Hypothetical Accident Conditions, as defined in 10 CFR 71.73
NCT	Normal Conditions of Transport, as defined in 10 CFR 71.71
rem	Roentgen equivalent in man. Named after Wilhem Roentgen. A deprecated unit used to measure the biological effects of ionizing radiation.
mrem	milli-rem. One thousandth of a rem.
mSv	millisievert SI unit 1 mSv is equivalent to 100 mrem
SAE	Society of Automotive Engineering
UNC	Unified Coarse Thread
USNRC	United States Nuclear Regulatory Commission

2.0 STRUCTURAL EVALUATION

This section identifies, describes, discusses, and analyzes the principal structural design features of the packaging, components and systems important to safety, ranked from most important to safety, to least important to safety (utilizing a graded approach to safety for the entire package). In addition this section will describe the various methods of compliance with the requirements of 10 CFR Part 71.

The structural evaluation of the BU650B package demonstrates compliance with the applicable performance requirements of 10CFR Part 71. Compliance with the applicable general standards (§71.43) and lifting and tie-down standards (§71.45) are demonstrated in Sections 2.4 and 2.5, respectively. The structural evaluation for Normal Conditions of Transport (NCT) Tests (§71.71) and Hypothetical Accident Conditions (HAC) Tests (§71.73) presented in Sections 2.6 and 2.7 respectively, demonstrate that the structural components of the package satisfy the applicable structural design criteria of ASME BPVC. Furthermore, under NCT Tests (§71.71), the package will experience no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. Therefore, the package satisfies the requirements of §71.43 (f) and §71.45(b)(1). The structural evaluation also shows that the cumulative package damage resulting from the HAC Test sequence (§71.73) does not result in an escape of radioactive material exceeding a total amount of A_2 in one week, nor does it result in an external radiation dose rate increase that would exceed 0.10 mSv/h at 1 meter from the external surface of the package. Thus, the package satisfies the requirements of §71.51(a)(2).

The structural evaluation of the package is performed by analysis using computational modeling software (CMS) and classical closed-form solutions (hand calculations). The analytic techniques used for the structural evaluation comply with guidance provided in United States Nuclear Regulatory Commission Regulatory Guide 7.9, (RegGuide) as supplemented by USNRC Interim Staff Guidance – 21 (ISG-21). The ANSYS Mechanical and ANSYS LS-DYNA PC computer programs are used for the structural evaluation of the package. ANSYS LS-DYNA is a well-benchmarked and widely used software for structural analyses of transportation packages for radioactive materials. Descriptions of these computer programs, including discussion of validation of codes, are provided in Section 2.12 and Section 3.3 of this document. The computer models used for the structural evaluation are identified and described in those documents.

The adequacy of the analytic techniques used to evaluate the package dynamic response to NCT and HAC free-drop and puncture tests is demonstrated by results of full-scale modeling tests identified above. The results confirm that the computer model provides accurate predictions of the Shielded Liner rigid-body response (carrier for radioactive sealed source(s)), the structural response of the BU650B package assembly, and the extent of damage sustained by the package.

2.1 Description of Structural Design

2.1.1 Discussion

The principal structural members important to the safe operation of the package are the Shielded Liner which contains the radioactive sealed source(s), the Lower Package Assembly with Closing Ring (closure), the Lid Assembly, and the Impact Limiters. The Shielded Liner provides the necessary radiation shielding component of the package, serving as the second layer of containment for the radioactive material contents (Sealed Sources in Special Form). Sealed Sources are manufactured and tested under 49 CFR 173.469 and 10 CFR 71.75, as appropriate.

Shielded Liner. The Shielded Liner provides the secondary containment boundary and principal shielding for the package. Shielded Liners of various configurations and sizes within those configurations are intended for use within the package. Each smaller size will be made from materials and methods equal to the largest configuration, thereby bounding the configuration by an extreme size. Variation will be determined by the radioactive output of the load to be carried and the intended end-use of the product. All configuration variances are intended to be computer modeled to ensure the variation has no negative impact on overall package safety. Typical Shielded Liners are constructed of lead, encased by fully welded carbon steel containment. The containment walls are a minimum thickness of 1/8" carbon steel at the cavity and ¼" carbon steel on the outer wall. The spaces between the inner cavity and outer wall are lead-filled in such manner that there are no voids. All Shielded Liners are verified by radiological assessment prior to use. Shielded Liners are discussed further in Section 2.1.1.1 and are identified on drawings located at Section 1.3.2.

Lower Package Assembly. The Lower Package Assembly consists of the Inner Liner, Outer Shell, Bottom Plate, and Closing Ring fabricated in accordance with the instructions contained in Section 7 of this document. The Inner Liner consists of 3/8" thick grade 304 stainless steel plate, rolled to form and then seam welded. The Inner Liner is attached to the Closing Ring via a grove weld placed at the inside of the Closing Ring. The bottom plate consists of a 3/8" thick grade 304 stainless steel plate, cut to dimension and then set over the Inner Liner in such manner as to create a "step" for installation of a fillet weld. The Outer Shell is then attached to the closing ring via groove weld at the top. The weld is then smoothed. The annular space created by the gap between the Inner Liner and Outer Shell is filled with a Kaolite 1600 slury in accordance with the Kaolite manufacturer's instructions. The Kaolite 1600 is cured in-situ. Once cured, the Kaolite 1600 is brick-like in consistency. The bottom plate, consisting of ½" thick stainless steel plate is set inside the bottom lip of the Outer Shell and then a fillet weld is installed, sealing the Kaolite 1600 between the inner and outer walls of the package. The materials and methods of fabrication ensure a rigid and protective package. The Lower Package Assembly is further identified on drawings located at Section 1.3.2.

Closing Ring (Closure). The Closure Ring is a sub-assembly of the Lower Package Assembly. The BU650B is closed by setting the Lid Assembly on top of the Closure Ring and then securing the Lid Assembly to the Closure Ring with 24 each, ¾"-10UNC grade 316 stainless steel bolts. The bolts penetrate the closing ring and anchor into 1.5" threaded anchors which are fabricated from grade 316 stainless steel rod. There is a 1/8" thick backing plate at the end of each anchor to prevent bolt intrusion into the annular space between the inner and outer package liner walls which is filled with the Kaolite 1600 thermal barrier material.

The Lower Package Assembly which includes the Closing Ring Assembly is further identified on drawings located at Section 1.3.2.

Lid Assembly. The Lid Assembly is fabricated from grade 304 Stainless Steel and has a 4" protrusion filled with Kaolite 1600 for thermal insulation purposes. Atop the lid is a 2" impact absorber, made from ¼" thick Grade 304 stainless steel ring and plate. This impact absorber serves two purposes: protection of the closure bolts and energy absorption from severe impact(s). There is a lifting ring fixed to the top center of the lid assembly for lifting the lid only. Appropriate markings provide adequate warning against attempting to lift the entire package with this ring. The primary or base plate used for the closure is fabricated from ½" thick Grade

304 stainless steel plate and contains 24 bolt holes for securing the lid to the closure ring. The Lid Assembly is further identified on drawings located at Section 1.3.2.

Impact Limiters. The Impact Limiter Assemblies are intended to be sacrificial and provide no other benefit to the package other than energy absorption occurring as a result of significant impact. Impact Limiters are constructed from grade 304 stainless steel, 12 gage, sheet metal; eight 1/8" x 3" x 3" angle supports; and foam (General Plastics FR 3712). The foam is poured in continuous batch until the impact limiter is completely filled (no voids). The foam is cured and then the ports used for installation and ventilation (3) are closed with a plastic plug designed to melt away and allow for the foam to emit accumulated gasses and intumesce during exposure to extreme heat. Impact Limiter mounting brackets ensure a rigid attachment to the Lower Package Assembly which minimizes rotational energy as a result of significant impact.

The Impact Limiters when attached to the Lower Package Assembly are intended to limit impact loads delivered to the Shielded Liner during HAC and NCT, and provide additional insulation to the Lower Package Assembly from the external effects of thermal events occurring as a consequence of HAC. The Impact Limiter Assembly is the primary component intended to absorb energy delivered to the package as a consequence of HAC (§71.73(c)(1)). As such, the Impact Limiter Assemblies are considered sacrificial and once expended, not relied upon as energy absorbers for tests subsequent to the 30' Drop Test. The structural design of these assemblies is described in the following sections. Impact Limiters are further identified at Section 1.3.2.

2.1.1.1 Shielded Liner Assembly.

Shielded liners are the second inner layer of containment and provide shielding for Sealed Source(s). For simplicity, only one configuration of Shielded Liner is provided with this application. Shielding is realized through the use of "Shielded Liners" which are manufactured in accordance with the performance standards identified in 49 CFR 173.410 and 173.412, DOT 7A Packaging, as a minimum standard of construction. J.L. Shepherd & Associates design specifications ensure that shielded liners meet or exceed these minimum performance standards as follows:

1) All shielded liners are fully welded, lead containments with exterior walls fabricated from a minimum of ¼" thick carbon steel (1017 or "cold roll" equivalent or better);

2) Each shielded liner core is lined with a minimum of 1/8" thick carbon steel or better;

3) Radiation Shielding (lead required) is as specified in the graphs provided in Section 5.5.2 and Section 5.5.3 and is designed to ensure that emitted radiation levels at a distance of one meter from the loaded package do not exceed 0.10 mSv/hour at any location along the package exterior as a consequence of HAC.

4) Lifting devices on the modeled shielded liner have a minimum safety factor of 1.5.; and, are based upon the following: The Shielded Liner as configured has two lifting eye sockets, 1" diameter. When fitted with lifting eyes of 1" diameter there is a safety factor of 1.5 on each lifting eye. Calculations supporting the above are at Section 2.12.5.

5) The closure mechanism found on this type of Shielded Liner has eight bolts, or studs with lock washers and nuts (SAE Grade 5 or better), through a plate which typically holds or retains a shielding plug. (See Figure 2-1). Shielding plugs are typically lead contained within a fully welded carbon steel jacket. Variations of this plug configuration consist of a tungsten versus lead shielding media. The tungsten configuration is nearly half the mass of the lead configuration and provides an equal or greater amount of shielding due to the difference of densities between the compounds. When complete, the shielded liner provides a well-protected transport mechanism for sealed sources. Gasses are not found within the package or the package contents. Gaseous expansion therefore is not considered or addressed in this report.

The Shielded Liner also serves as the secondary containment. Sealed sources and sealed source assemblies are secured in racks or spiders (See Figure 2-2), or Bailer cans so that movement, if any, is restricted to less than ½". This minimizes the potential for damage to the source capsule or source capsule assembly and, therefore, enhances containment of the radioactive materials during transport. There is a stepped interface between the inner cavity of the Shielded Liner and

Closure Plug to minimize radiation streaming through the closure lid of the Shielded Liner.

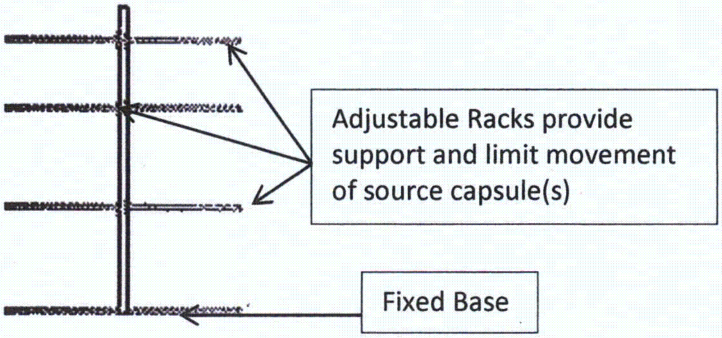
Shielded liners are designed to withstand the effects of free-fall drop (end, side or angle) to an unyielding surface from a distance of one meter, withstand a puncture from a falling object from a distance of one meter, and thermal effects of exposure to 158°F continuously, water spray, and stacking, without loss of shielding due to slumping resulting from impact; or, as a result of exposure to extreme heat for a period of thirty minutes.

Figure 2-1

Typical Shielded Liner Closure Lid and Plug Assembly, Lead filled.

Figure 2-2

Typical Source Holder (Spider)



2.1.1.2 Package Assembly (Lower Package Assembly)

This part of the package assembly consists of inner and outer right cylinder constructed from 3/8" thick grade 304 Stainless Steel Plate, rolled to form and fully seam welded in accordance with applicable (ASME and ASTM) specifications. The Package Assembly begins at the extreme exterior, or Outer Shell, which consists of 3/8" grade 304 stainless steel plate, rolled to form and seam welded. The Outer Shell Wall is constructed from 3/8" thick grade 304 Stainless Steel plate, rolled to form, then seam welded. All Lower Package Assembly welds are fabricated according to American Welding Society (AWS) and or ASME BPVC Specification(s) as appropriate to the weld requirement. The bottom plate is fabricated from ½" thick grade 304 Stainless Steel plate and nests within the outer shell wall. The bottom plate is fully welded in accordance with the above. The top of the Lower Package Assembly consists of the Closing Ring which is welded to both the Inner and Outer Shells. Contained between the inner and outer shell is a material known as Kaolite 1600 (approximately 4" thick) which acts as a thermal barrier. The inner layer of protection is the inner liner which is constructed of 3/8" thick stainless steel (grade 304), rolled to form and seam welded. The bottom plate of the inner liner is constructed from 3/8" thick grade 304 Stainless Steel as well.

2.1.1.3 Lid Assembly

The package as designed has a rigid closure. At the most extreme top of the lower package assembly is a flanged lid assembly, fabricated from ½" thick grade 304 stainless steel plate which is held to the package by twenty-four grade 316 stainless steel Bolts (125,000 psi rated). The bolts are nested into deep, 316 stainless steel anchors, having 3/8" thick walls, which are welded to the interior section of the closing flange prior to installation of the closing flange. At the bottom, interior section of the lid is a 4" step which houses Kaolite 1600, a thermal barrier material. The Kaolite 1600 is poured as a slurry and then cured in-situ according to manufacturer instructions. The bottom is then closed by fully welded covering (3/8" grade 304 stainless steel).

Once the exterior closure is complete a tamper-proof seal is affixed. This seal is serialized so that a visual indication becomes obvious in event of tampering or unauthorized access.

2.1.1.4 Impact Limiter Assembly

The Impact Limiters are designed to absorb the shock and energy generated from an impact equivalent to a drop from thirty feet onto an unyielding surface. The impact limiters consist of a poured polyurethane foam equivalent to 12 lbs per cubic foot density (+/-15%), surrounded by a fully welded 12 gage, grade 304 stainless steel shell, with eight 1/8" x 3" x 3" grade 304 stainless steel angle supports. The assembly is then fitted to the lid and bottom of the outer shell by attachment at four points at the top-center and bottom-center of the package. Each point of attachment is rigid and held by grade 316/316L, 9/16" diameter stainless steel pins and clips.

The foam within the Impact Limiter is manufactured by General Plastics of Seattle, Washington. The specification used is General Plastics, Model FR3700 (3712). Specific to the design requirements a test sample of foam is extracted from each lot and tested in order to ensure that rated capabilities are achieved from each batch or "pour". The foam lots are tested in accordance with ASTM specifications identified in J.L. Shepherd & Associates Engineering Specification ES-002. Tested measurements include compressive strength measurements at both parallel and perpendicular to grain and density. There are three ventilation ports installed at the away-facing top and bottom ends of the Impact Limiters. These ports are covered by 2" to 3" diameter plastic plugs which are intended to begin melting at or before 800°F in order to allow flammable gasses to escape and permit intumescence of the polyurethane foam enclosed within the Impact Limiters.

2.1.2 Design Criteria

The design criteria used for the structural design of the package is selected in accordance with the codes and standards identified in Tables 2-4A and 2-4B. All structural analyses of the package are performed for the applicable NCT test [§71.71] and HAC tests

[§71.73]. The combination of initial conditions used for the structural evaluation of each NCT and HAC test are discussed in Section 2.1.2.1. The stresses in the package structural components are calculated for the NCT and HAC load combinations and compared to the allowable stress design criteria described in Section 2.1.2.2. Other structural failure modes, such as brittle fracture, fatigue, buckling are evaluated using the design criteria discussed in Sections 2.1.2.3 through 2.1.2.5. All structural stress evaluations are based upon ANSYS LS DYNA computer model. See Section 2.12.4.

2.1.2.1 Load Combinations

The load combinations used for the structural evaluation of the package are developed in accordance with Regulatory Guide 7.8. The load combinations are based on Table 1 of Regulatory Guide 7.8, with additional load combinations for intermediate initial conditions that could possibly create a more limiting case for the package design. The NCT and HAC combinations are summarized in Table 2-1 and Table 2-2. (Tables 2-2 and 2-3 are provided in compliance to NRC Reg Guide 7.8 format.) All assessments are made assuming a 450 watt decay heat.

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Table 2-1

LOAD COMBINATIONS FOR NORMAL CONDITIONS OF TRANSPORT

("X" indicates presence of load). All assessments made assuming a 450 watt Decay Heat Load.

Normal or Accident Condition	Initial Conditions [1]								
	Ambient Temp.		Insolation[2]		Decay Heat		Internal Pressure [3]		Fab. Stress[4]
	38°C	-29°C	Max	Zero	Max	Zero	Max	Min	
Hot Environment (38°C Ambient)			X		X			x	X
Cold Environment (-40°C Ambient)				X	X			X	X
Reduced Internal Pressure	X		X		X			X	X
Increased Ext. Pressure		X		X	X			X	X
Vibration & Shock	X		X		X			X	X
		X		X				X	X
Free Drop	X		X		X			X	X
		X		X	X			X	X

Notes:

1. Initial package temperature distributions are considered to be at steady-state.
2. Maximum insolation in accordance with §71.71(c)(1).
3. Internal pressure is consistent with the other initial conditions being considered. Minimum internal pressure is taken as atmospheric pressure.
4. Stresses due to assembly of the major components of the packaging, including stresses due to closure bolt pre-load.

Table 2-2
Load Combinations or Hypothetical Accident Conditions
("x" indicates presence of load)

Normal or Accident Condition	Initial Conditions(1)								
	Ambient Temperature		Insolation(2)		Decay Heat		Internal Pressure(3)		Fab. Stress(4)
	38°C	-29°C	Max	Zero	Max	Min	Max	Min	
Free Drop	X		X		X			X	X
		X		X		X		X	X
Puncture	X		X					X	X
		X		X		X		X	X
Thermal	X		X		X			X(5)	X

Notes:
1. Initial package temperature distributions are considered to be at steady-state.
2. Maximum insolation in accordance with §71.71.(c)(1).
3. Internal pressure is taken as atmospheric pressure, all conditions.
4. Stress due to assembly of components of the packaging, including closure bolt pre-load.
5. Maximum internal pressure for the HAC thermal condition cannot be measured due to the chemical composition of the two isotopes under consideration (Co-60 as a sealed source in Special Form and Cs-137 as a sealed source in Special Form).

2.1.2.2 Allowable Stresses

The BU650B has no pressure-retaining components. Non-pressure-retaining circumferential welds are designed in accordance with the applicable requirements of Subsection WB of the ASME BPVC. All package structural components that are not relied upon for containment are designed in accordance with allowable stress design criteria for Class 2 plate and shell-type supports from Subsection NF of the ASME BPVC. The NCT and HAC allowable stress design criteria for the package components are summarized in Table 2-3.

Subsections NF and WB of the ASME BPVC impose stress limitations on primary membrane, local membrane, membrane (primary or local) plus bending, and primary plus secondary stress intensities. To demonstrate conformance to the ASME BPVC limits, it is necessary to determine the required code stress intensities at critical cross-sections of the package. Since the critical cross-sections are load-condition-dependent, several "stress evaluations" were made in order to establish that all critical locations have been evaluated for every load condition. The evaluation revealed that there are no sections of the package that receive stresses in an amount sufficient to result in a load condition dependency. In fact, the package presents only one or two component items that approach allowable stress limits. Therefore the stress evaluation has been limited to key components which are illustrated in Table 2-3. For Shielded Liner buckling evaluation, membrane stress components at the mid-length of the Shielded Liner inner and outer sections are used.

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Table 2-3

Allowable Strain, Component Evaluation, Most Damaging Configuration Realized (15° Top Drop)

	Rated Yield (psi)	**Design Yield** (% of psi)	**Actual** (%)	**Rated Stress** (psi)	**Design Stress** (% of psi)	**Actual** (%)
Component						
Grade 304 Stainless Steel Inner & Outer Shell	77,000	50%	6%	90,000	50%	0.5%
Kaolite 1600	40,000	100%	60%	7,405	100%	32%
GP Last-A-Foam FR 3700	1447	100%	66%	1407	100%	66%
Weld Joints, Pkg	90,000	50%	30%	90,000	50%	30%
Pkg Closure Bolts	125,000	20%	17%	70,000	20%	3%
Carbon Steel	30,000	50%	53%	38,500	50%	41%
12 Gage, 304SS Impact Limiter Shell	11,250	100%	100%	22,000	100%	100%
Lead Shielding	2,200	12.5%	2.5%	4,000	12.5%	0.05%
Alum. Source Holder (6061)	33	6.37%	0%	70.4	6%	0%
.020 Alum Source Cage Wall	39.6	5%	0%	17.6	5%	0%
Bolts/Studs Shielded Liner	120,000	20%	7%	70,000	20%	12%
Nuts, Shielded Liner	120,000	20%	7%	70,000	20%	12%

*Note: 1. One weld joint, on the designed sacrificial ring on lid top experienced at 90% strain. All other welds at or below 30%.

2. Figure 45 of DAC-P09YCW01-0001-000-00, Section 2.12.4, reflects strains of 53% applied to the edge of the closing plate on the Shielded Liner. There is no indication of failure of the component. Only localized stress notations.

The section stresses at each stress evaluation location are obtained using the ANSYS "stress linearization" post-processing feature. The stress linearization provides membrane, bending, membrane plus bending, peak and total stress intensities at each section. These stresses are classified in accordance with the ASME BPVC for comparison to applicable allowable stress design criteria as follows:

Membrane Stress Intensity

There are no membrane stress features within the secondary and tertiary containments. Any primary membrane stress intensities, as defined, are limited to the Sealed Source(s) only and are considered by 49 CFR 173.469 and §71.75. Those considerations are not addressed in this SAR as this application is for the transport of sealed sources manufactured under the requirements of 49 CFR 173.469 and 10 CFR 71.75.

Membrane Plus Bending Stress Intensity

The membrane plus bending stress intensities at each section are classified as either primary (P_m+P_b) or secondary (P_m+P_b+Q) based upon the location in the structure. Bending stresses at gross structural discontinuities, such as flange-to-shell junctions and junctions between shells and end plates are classified as secondary. Potential membrane plus bending stress intensities at the weld closure of the sealed source(s) stress sections are classified as primary, and are considered in the performance criteria specified by 49 CFR 173.469 and 10 CFR 71.75.

Total Stress Intensity

Total stress intensities include primary stress, plus secondary stress, plus peak stresses. In accordance with ASME BPVC, these stresses are objectionable only as a possible source of a fatigue crack or brittle fracture. Accordingly, evaluation of cyclic loading is not required for the BU650B package due to use of austenitic stainless steels.

Using the critical sections from each load case, minimum design margins are calculated and reported for all bounding load combinations. The design margin (D.M.) is defined as follows:

$$\text{D.M.} = \left(\text{Allowable Value / Calculated Value}\right)-1;$$

where the allowable and calculated values are in consistent units.

The Impact Limiter Assembly and Lower Package Assembly are designed to deform plastically and absorb the kinetic energy when subjected to the NCT free drop, HAC free drop, and HAC puncture drop load conditions. Therefore, a strain based design criteria has been used for both the Impact Limiter and the Lower Package Assembly. The maximum crush depth of the polyurethane foam in the Impact Limiter is 70% of the nominal foam section thickness. In cases of highly localized foam crush, e.g., that due to the HAC hot top-corner drop impact, the maximum foam crush depth may not exceed 80% of the nominal foam section thickness. The maximum strain in the package stainless steel shell components is limited to the lower-bound maximum elongation from the ASME BPVC material specifications for all material options.

The Lower Package Assembly (package) closure bolts are designed to satisfy the Service Level A, allowable stress design criteria for Class 2 supports from Subsection NF of the ASME BPVC for NCT. The bolt allowable stress design criteria for NCT is established at 20% yield. The maximum strain in the package closure bolts is limited to the bolt material maximum elongation from the ASME BPVC material specification. In addition, the average shear stress in the package closure bolts for HAC is limited to the lesser of $0.6S_y$ and $0.42S_u$ in accordance with Appendix F, ASME BPVC.

Weld Joints, Package. The BU650B package component experiencing the greatest strain on weld joints is the Cask Lid Outer Cylinder. This is the 2" tall energy absorber that sits atop the lid assembly. At localized points, ranging from 0°, 5°, and 10° angle 30' drops, the fillet weld securing the verticle wall (2") experiences strains of 47%, 78% and 85% respectively. Other drop angles are in excess of the 50% design criteria, but again, are localized to small linear sections of the weld. At no point is a failure of the weld reported. It is important to note that this appurtenance is designed to fail in order to protect the lid assembly, closure joint and closure bolts, and therefore has no structural significance.

Carbon Steel Surfaces. At points between 0° and 10°, the carbon steel Shielded Liner Lid (plug) Assembly experiences localized plastic strains of 53%. The affected areas are the immediate areas of contact between the Shielded Liner Lid and the Shielded Liner Impact where it contacts the Shoring Assembly within the main package body. Additionally, the strain applied is as a consequence of HAC drop and applied largely against the Impact Ring designed to protect the Shielded Liner lid bolts from shear and then transmitted to the Shielded Liner Lid at the edges.

2.1.2.3 Buckling

The Shielded Liner, Inner Shell, and Outer Shell are evaluated for buckling in accordance with the requirements of ASME BPVC Case N-284-1. The parameters of the package inner and outer shells used for the buckling evaluation are summarized in Sections 1.3.8 and 1.3.9 of this document. Capacity reduction factors are calculated in accordance with Section-1411 of ASME BPVC Case N-284-1 to account for possible reductions in the capacity of the shells due to imperfections and nonlinearity in geometry and boundary conditions. Plasticity reduction factors, which account for nonlinear material properties when the product of the classical buckling stresses and capacity reduction factors exceeds the proportional limit, are calculated by the computer model in accordance with Section-1610, ASME BPVC Case N-284-1. The theoretical buckling stresses of the package inner and outer shells under uniform stress fields are calculated in accordance with Section 1712.1.1, ASME BPVC Case N-284-1. Package shell lower-bound material properties at an upper bound temperature of 85°C are conservatively used to determine the buckling factors and theoretical buckling stresses.

The allowable elastic and inelastic buckling stresses for NCT and HAC are calculated in accordance with the formulas given in Section 1713.1.1 and Section 1713.2.1, ASME BPVC Case N-284-1. The allowable buckling stresses include safety factors of 2.0 for HAC as a minimum in accordance with Section–1400 of ASME BPVC Case N-284-1. The interaction ratios for elastic buckling and inelastic buckling are calculated using the highest values of compressive stress and shear stress from the finite element analysis solutions in accordance with the formulas given in Section–1713.1.1 and Section–1713.2.1, ASME BPVC Case N-284-1.

2.1.2.4 Fatigue

2.1.2.4.1 Structural Components, Other Than Bolts

Analysis of the package structural components for cyclic service is not required because the conditions stipulated in WB–3321.0(d)(1) through (6) are met. The analysis is conservatively based on the assumption that the package will be used for 20 years and be used for one shipment per week for a total of 1040 shipments of sealed sources in special form having a maximum decay heat of 450 Watts. The analysis is summarized as follows:

1. The number of atmospheric-to-operating cycles, which is equal to the number of shipments (1040 cycles), is less than 13,688 cycles, corresponding to an S_a value of $3S_m$ = 414 MPa for grade 304 and grade 316 stainless steel over the temperature range of interest. Thus, condition (1) of WB-3221.9(d) is met.

2. Normal operating pressure fluctuation cycles in the package resulting from diurnal fluctuations in ambient conditions (temperature and insolation) are not applicable to this package design. The package has no sealing surfaces or sealing requirement due to the limitation of shipment of sealed sources in special form only. Thus, it is assumed that the package will experience one normal operating pressure fluctuation per day, or 7,300 cycles over its 20-year service life. Therefore, condition (2) of WB-3221.9(d) is met.

3. The temperature difference between any two adjacent points on the Shielded Liner during start-up and shut-down is not relevant to the design presented due to the limitation of transporting sealed sources in special form only. Sealed Sources in Special Form are manufactured under quality assurance and manufacturing criteria defined in 49 CFR 173.469 and 10 CFR 71.75. When properly tested for seal integrity, sealed sources in special form of the size requested to be included within the package

certificate do not pose a risk of expansion and rupture under NCT. Thus, condition (3) of WB-3221.9(d) is met.

4. Normal operating temperature fluctuation cycles in the package result from diurnal fluctuations in ambient conditions (temperature and insolation). Thus, it is assumed that the package Shielded Liner when loaded within the package will experience one normal operating temperature fluctuation per day, or 7,300 cycles over a 20-year service life. The thermal evaluation of the package shows that the temperature difference in the package does not vary significantly under NCT and is less than 10°C. Thus, condition (4) of WB-3221.9(d) is met.

5. The BU650B package relies upon the sealed source manufactured under 49CFR173.469 and 10 CFR 71.75 as the containment system. As such, there are no dissimilar materials known to have been used in the structural fabrication of sealed sources. Thus condition (5) of WB–3221.9(d) is met.

6. The only significant cyclic mechanical loads the package is subjected to during normal operation are those resulting from handling and NCT vibration. The only handling operation that creates any significant stress in the shielded liner or package assembly is the process of lifting. The number of lift operations performed for each shipment is small, but conservatively assumed to be 10 or less per shipment for a maximum of 10,400 lifting cycles over a 20-year service life. As discussed in Section 2.6.5, a bounding 10g vertical vibration load is conservatively assumed for the package evaluation. It is conservatively assumed that the package will experience a total of 10^6 cycles of vibration loading per shipment with a magnitude of 10g or 1.04E10 cycles over a 20-year service life. The value of S_a for 1E10 cycles and higher, for austenitic stainless steels is 94 MPa per Figure I-9.2.2 (curve C) of Appendix I of the ASME BPVC. As discussed in Section 2.5.1 and Section 2.6.5, the maximum stress intensity in the Package Assembly due to lifting and vibration loading

are 9 MPa and 11 MPa, respectively. The value of S_a for 1E10 cycles and higher for carbon steel used in the manufacture of the Shielded Liner is 205 MPa. These stresses are equal to or slightly less than one-tenth the S_a value for the total number of mechanical load cycles. Therefore, condition (6) of WB-3221.9(d) is met.

The BU650B package as designed is capable of carrying a maximum payload of 6,700 pounds which includes a shielded liner containing radioactive contents and materials necessary to secure the shielded liner in event of fall and/or impact. Payloads may vary from approximately 400 pounds to 6,700 pounds as determined by shielding requirements necessary to meet required shipping limitations of radioactive emissions (10CFR71.47).

2.1.2.4.2 Package Closure Bolts

The package closure bolts are subjected to cyclic loading due to start-up/shut-down cycles of bolt preload and temperature, normal fluctuation cycles of temperature and cyclic loading due to vibration normally incident to transportation. Although designed as tertiary containment closure system, BU650B package closure bolts are evaluated for fatigue failure due to cyclic loading using the methods of WB-3221.9(e) in accordance with the requirements of WB-3232(d)(2). In accordance with the requirements of WB-3232(d)(2)(d), a fatigue strength reduction factor of 4.0 is used for the BU650B package closure bolt fatigue evaluation.

Start-up/Shut-down Cycles

The package is conservatively assumed to undergo 1,040 start-up/shut-down cycles over its 20-year design life. The maximum stress in the package closure bolts due to the maximum bolt preload, MNOP, and NCT heat loading is 110 MPa. The minimum stress in the closure bolts for start-up/shut-down cycles is zero. Thus, the alternating stress in the closure bolts for start-up/shut-down cycles, including a fatigue reduction factor of 4 is 218 MPa. The allowable number of start-up-shut-down cycles for an alternating stress of 218 MPa is 872 MPa per Figure I-9.4 of Appendix I of the ASME BPVC. Therefore, the BU650B package closure bolt usage factor for start-up/shutdown cycles is 0.25, which negates the need for periodic bolt replacement.

<u>Thermal and Pressure Fluctuations – Normal Operating Cycles</u>

Normal operating temperature and pressure fluctuations in the BU650B package result from diurnal ambient temperature fluctuations. The package is conservatively assumed to undergo one normal operating cycle for every day of its 20-year design life, or 7,300 cycles. The maximum temperature fluctuations of the package in the region of the closure bolts and the bulk average temperature of the BU650B package cavity both fluctuate by approximately 10°C during each diurnal cycle. This temperature fluctuation produces an alternating stress in the closure bolts. The maximum stress in the package closure bolt due to the maximum bolt preload, MNOP, and NCT heat loading (based on a bounding bolt temperature of 68.3°C) is 209 MPa. At room temperature (21°C) the bolt stress due to the maximum preload of 7,219 N is 92 MPa. Thus, a temperature change of 47.3°C increases the bolt stress by 117 MPa (209 MPa – 92 MPa). The stress range due to a 10°C temperature fluctuation is 25 MPa (=117 x 10/47.3). Thus, the alternating stress in the closure bolts for normal operating thermal and pressure cycles, including a fatigue reduction factor of 4, is 50 MPa. The allowable number of normal operating cycles for an alternating stress of 50 MPa is 184,062 per Figure I-9.4 of Appendix I of the ASME BPVC. Therefore, the BU650B package closure bolt usage factor for normal operating thermal and pressure cycles is 0.04 (7,300/184,062), negating the need for periodic bolt replacement.

Vibration Cycles

The results of the BU650B package closure bolt evaluation show that NCT vibration loading results in only a 1 MPa increase in the closure bolt stress. Thus, the alternating stress in the closure bolts for NCT vibration cycles, including a fatigue reduction factor of 4, is Salt3 = 2.0 MPa. The value of Sa at 1E6 cycles is 37 MPa per Figure I-9.4 of Appendix I of the ASME BPVC. Since Salt3 is much lower that Sa at the endurance limit of 1E6 cycles, the usage factor for NCT vibration is insignificant (i.e., U3 = 0.00), negating the need for periodic bolt replacement.

Cumulative Usage Factor

The cumulative usage factor for cyclic loading of the BU650B package closure bolts is: U = U1 + U2 + U3 = 0.25 + 0.04 + 0.00 = 0.29. Since the cumulative usage factor is less than 1.0, the package closure bolts will not fail due to fatigue during their 20-year design life.

2.1.2.4.3 Shielded Liner Closure Bolts

The shielded liner closure bolts are subjected to cyclic loading due to start-up/shut-down cycles of bolt preload and temperature, normal fluctuation cycles of temperature and cyclic loading due to vibration normally incident to transportation. Although designed as the secondary containment closure system the shielded liner closure bolts are evaluated for fatigue failure due to cyclic loading using the methods of WB-3221.9(e) in accordance with the requirements of WB-3232(d)(2). In accordance with the requirements of WB-3232(d)(2)(d), a fatigue strength reduction factor of 4.0 is used for the shielded liner closure bolt fatigue evaluation.

Start-up/Shut-down Cycles

Because of multiple use potential (storage, source transfer, etc.) the shielded liner is conservatively assumed to undergo 1,000 start-up/shut-down cycles over a one year period. The maximum stress in the shielded liner closure bolts due to the maximum bolt preload, MNOP, and NCT heat loading is 112 MPa. The minimum stress in the closure bolts for start-up/shut-down cycles is zero. Thus, the alternating stress in the closure bolts for start-up/shut-down cycles, including a fatigue reduction factor of 4 is 224 MPa. The allowable number of start-up-shut-down cycles for an alternating stress of 224 MPa is 896 MPa per Figure I-9.4 of Appendix I of the ASME BPVC. Therefore, the shielded liner closure bolt usage factor, assuming annual bolt changes, for start-up/shutdown cycles is 0.60.

Thermal and Pressure Fluctuations – Normal Operating Cycles

Normal operating temperature and pressure fluctuations in the shielded liner result from diurnal ambient temperature fluctuations. The shielded liner is conservatively assumed to undergo one normal operating cycle for every day of its 20-year design life, or 7,300 cycles. The maximum temperature fluctuations of the shielded liner in the region of the shielded liner closure bolts and the bulk average temperature of the shielded liner cavity both fluctuate by approximately 10°C during each diurnal cycle. This temperature fluctuation produces an alternating stress in the closure bolts. The maximum stress in the shielded liner closure bolt due to the maximum bolt preload, MNOP, and NCT heat loading (based on a bounding bolt temperature of 68.3°C) is 209 MPa. At room temperature (21°C) the bolt stress due to the maximum preload of 7,219 N is 92 MPa. Thus, a temperature change of 47.3°C increases the bolt stress by 117 MPa (209 MPa – 92 MPa). The stress range due to a 10°C temperature fluctuation is 25 MPa (=117 x 10/47.3). Thus, the alternating stress in the shielded liner closure bolts for normal operating thermal and pressure cycles, including a fatigue reduction factor of 4, is 50 MPa. The allowable number of normal operating cycles for an alternating stress of 50 MPa is 184,062 per Figure I-9.4 of Appendix I of the ASME BPVC. Therefore, the shielded liner closure bolt usage factor for normal operating thermal and pressure cycles is 0.04 (7,300/184,062), negating the need for periodic bolt replacement.

Vibration Cycles

The results of the shielded liner closure bolt evaluation show that NCT vibration loading results in only a 1 MPa increase in the closure bolt stress. Thus, the alternating stress in the closure bolts for NCT vibration cycles, including a fatigue reduction factor of 4, is Salt3 = 2.0 MPa. The value of Sa at 1E6 cycles is 37 MPa per Figure I-9.4 of Appendix I of the ASME BPVC. Since Salt3 is much lower that Sa at the endurance limit of 1E6 cycles, the usage factor for NCT vibration is insignificant (i.e., U3 = 0.00) negating the need for periodic bolt replacement.

Cumulative Usage Factor

The cumulative usage factor for cyclic loading of the shielded liner closure bolts is: U = U1 + U2 + U3 = 0.60 + 0.04 + 0.00 = 0.64. Since the cumulative usage factor is less than 1.0, the shielded liner closure bolts will not fail due to fatigue during their one-year design life.

2.1.2.5 Brittle Fracture

The BU650B package is designed in consideration of the fracture toughness requirements of Regulatory Guide 7.11 and NUREG/CR-1815. In consideration of those requirements, JLS&A has opted to utilize austenitic stainless steels in the manufacture of the BU650B. With the exception of the Shielded Liner, which when loaded maintains a static temperature of 108°C, all package components are made from grade 304 or 316 stainless steels which do not undergo a ductile-to-brittle transition in the temperature range of interest for load conditions that involve impact loads, i.e., down to -20°F (-29°C), and, thus, do not need to be evaluated for brittle fracture. As stated in Regulatory Guide 7.11 [2.9], "Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle fracture."

The package closure bolts and anchors are fabricated from grade 316 stainless steel and are obtained from JLS&A Quality Assurance-approved vendors capable of certifying their material integrity.

The Shielded Liner, when present, is loaded with sufficient radioactive material to generate a decay heat output ranging from 0°C to 128°C (steady state). For those situations where the radiation output allows for the use of less lead or lead equivalent shielding, the shielded liner will have less mass, but be of construction equal to that of the largest shielded liner used. Consequently, decay heat, even at a low rate, will keep the shielded liner above temperatures approaching brittle fracture. Additionally, due to the method of restraining the shielded liner, the potential for damage and resulting brittle fracture of shielded liner components becomes remote as any movement of shielded liners during HCT/NCT is limited to ½" or less vertically and less than 2" horizontally.

2.1.2.6 Elements of Construction.

(a) The BU650B package is constructed such that any component is capable of supporting the package at its maximum gross weight (~12,500 pounds). This means that the Impact Limiters are capable of supporting the maximum gross weight of the package at rest when fully loaded and closed.

(b) Likewise, all welded joints must be capable of withstanding the loads applied as a consequence of both normal use (NCT) and accident conditions (HAC).

(c) The closure mechanism is designed such that after significant impact, it can be opened without the need for sawing or cutting other package elements. All structural elements are made from grade 304 stainless steel and fully welded utilizing traditional arc welding methods to ensure strength of welded surfaces.

2.1.2.7 Maximum Allowable Stresses and Strains are expressed as a percentage of ultimate yield (tensile). Individual components are identified separately in order of importance to safety. Consideration is not given to brittle fracture due to the presence of austenitic stainless steels used as primary environmental package components. The only location where a carbon steel is used is within the shielded liner which, when loaded will stabilize with an elevated temperature due to decay heat of the carried isotope.

2.1.2.8 Decay Heat. The BU650B package must be capable of withstanding the temperatures associated with a 450 watt payload (128°C). This capability to be measured after stabilization.

2.1.3 Weights and Centers of Gravity

The BU650B package is a symmetrical series of right cylinders, beginning with an inner diameter of 35 inches and extending to an extreme outer diameter of 69 inches. The height of each cylinder varies beginning with the package Inner Shell at approximately 55 inches and extending to 63 inches at the Outer Shell and an overall height of approximately 90 inches with Impact Limiters installed. The main package body (Inner and Outer Shell Assemblies, complete with thermal barrier and weldment) weighs approximately 4,645 pounds. With Impact Limiters installed the weight grows to ~ 5,074.52 pounds. When fitted with maximum payload capability of ~ 6,713.60 pounds, the combined weight of the package is ~ 12,005.33 pounds. A table of component weights and is found at Appendix 2.12.2. Package Drawings located at Section 1.3.2 contain dimensions of package features.

Package center of gravity when fully loaded can be found approximately 32.5 inches from the extreme lower assembly with Impact Limiters installed. Exact component weights and locations of centers of gravity can be found on drawings relating to the BU650B Lower Package Assembly and the BU650B Shielded Liner Assembly. Weights of Impact Limiters can be found on drawing BU660B-IL. (See Appendix 1.3 for drawing information).

2.1.4 IDENTIFICATION OF CODES AND STANDARDS

The BU650B package is intended to transport sealed sources having a maximum decay heat output of 450 watts (29,250 Ci, Co-60; and 94,000 Ci, Cs-137, limited to less than 30,000 Curies), is designed, fabricated, tested, and maintained in accordance with codes and standards that are appropriate for transportation packages with Category III container contents. The design criteria for the package is discussed in Section 2.1.2. The load combinations used in the package structural evaluation are developed in accordance with Regulatory Guide 7.8, as discussed in Section 2.1.2.1. The buckling evaluation of the package cylindrical shells is performed in accordance with ASME BPVC Case N-284-1, as discussed in Section 2.1.2.3. Fracture toughness of the package components is evaluated in accordance with the requirements of Regulatory Guide 7.11 and NUREG/CR-1815 for Category III packages.

The package, as designed, does not provide primary containment for radioactive materials. Radioactive materials intended to be shipped in the BU650B package must be Sealed Sources meeting Special Form criteria, and manufactured in accordance with 49 CFR 172.469 and 10 CFR 71.75.

The BU650B package relies upon a Shielded Liner to provide gamma shielding. All Shielded Liner components are fabricated, installed, and tested in accordance with standard industry practices (minimum DOT 7A standard). Testing of the gamma shield is performed to assure that it satisfies the requirements for radiological shielding integrity, materials of construction, configuration and control. In addition, the soundness of the gamma shielding is demonstrated through measurement of the radioactive output and visual inspection of the component surfaces for unacceptable flaws (e.g., voids, cracks, or porosity).

The Kaolite 1600 material that fills the BU650B package base and lid shells is fabricated, installed, and tested in accordance with the manufacturer's instructions. The Kaolite 1600 is installed in the annular space between the inner and outer shell walls as a slurry. It is then dried and cured in-situ, in accordance with manufacturer's instructions. When complete, the Kaolite 1600 presents a thermal barrier material consisting largely of cement and vermiculite blend which will, in event of fracture, self-fill and prevent heat paths to the center of the package.

A compliance requirements summary, Table 2-4A and 2-4B, is provided to demonstrate how the BU650B package meets the ASME BPVC requirements and issues.

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Table 2-4A

BU650B ASME Boiler And Pressure Vessel Code, Section III, Division 1, Compliance Requirement Summary.

Item	ASME BPVC Requirement or Issue	Alternative Compliance Basis	ASME BPVC Sections
1	ASME BPVC Section III, Division 1, uses the following terminology that is not consistent with terminology used for the BU650B package:	The equivalent terminology or compliance basis used for the BU650B package are as follows:	
	(a) "Owner's Certificate"	(a) J.L. Shepherd & Associates will notify USNRC of the intent to design and fabricate a package, but will not seek an Owner's Certificate from ASME.	NCA-1210 & NCA-3230
	(b) "Design Specification"	(b) The information typically contained in the ASME BPVC Design Specification shall be included in the BU650B Safety Analysis Report (SAR).	NCA-1210 & NCA-3250
	(c) "Review of Design Report" and Design Report"	(c) The information typically contained in an ASME BPVC Design Report shall be included in the BU650B SAR and submitted for review and approval by USNRC.	NCA-1210, NCA-3260 & NCA-3350
	(d) "Certificate Holder" or "Owner"	(d) J.L. Shepherd & Associates bears the responsibilities associated with a "Certificate Holder" or "Owner" relative to the package with exceptions as noted.	Throughout
	(e) "Certificate of Authorization"	(e) Replaced by USNRC-issued Certificate of Compliance (COC).	Throughout
	(f) "Data Report" and "Stamping"	(f) Replaced by a Final Records Package and J.L. Shepherd & Associates COC for each fabricated package.	NCA-1210 & NCA-8000

Item	ASME BPVC or Requirement Issue	Alternative Compliance Basis	ASME BPVC Sections
2	Metallic materials shall be manufactured to an SA, SB, or SFA Specification, or any other material specification permitted by this Section. Such material shall be manufactured, identified, and certified in accordance with the requirements of this Section.	USNRC NUREG/CR-3854 via NUREG-1609 permits the use of ASTM materials for the fabrication/construction of the non-containment structural components of the package otherwise governed by the applicable requirements of ASME BPVC Section III, Division1, Subsection NF.	NCA-1221
3	Metallic materials produced under an ASTM designation may be accepted as complying with the corresponding ASME Specification, provided that the ASME Specification is designated as being identical with the ASTM Specification for the grade, class, or type produced and provided that the material is confirmed as complying with the ASTM Specification by a Certified Material Test Report or Certificate of Compliance from the Material Organization.	See Items 2 and 8.	NCA-1221.1
4	The package Impact Limiter Assembly is constructed to the requirements of Subsection NF, but not designed to the requirements of Article NF-3000 or Appendix NF-III.	The package Impact Limiter Assembly is designed by analysis and confirmed by scaled test to provide sufficient crush strength and structural integrity.	NF-3000 Appendix NF-III
5	The maximum temperature of the metal shall not exceed the maximum temperatures listed in the applicable tables of Section II, Part D, Subpart 1. However, the package is designed for a HAC fire that is not within the scope of the loading conditions typically considered for components designed in accordance with ASME BPVC Subsection NF.	The short-term allowable temperature limits for the package materials that are used for the HAC evaluation are defined in the calculation analysis and SAR. Otherwise, the load conditions as defined do not apply to the package under consideration as the package has a thermal limitation of 450 watts decay heat under NCT.	NF-3112.1
6	The ASME BPVC requires that the Design Specification be certified by one or more Registered Professional Engineers	The Design Specification for the BU650B shall be prepared and verified by persons qualified in accordance with the J.L. Shepherd & Associates 10CFR71 Quality Assurance Program	NCA-3255

Item	ASME BPVC or Requirement Issue	Alternative Compliance Basis	ASME BPVC Sections
7	ASME BPVC requires that the Owner or designee review the Design Report for compliance with the Design Specification.	The Design Report (DAC from Y-12) for the package shall be prepared and verified by personnel qualified in accordance with the USNRC-approved J.L. Shepherd & Associates Quality Assurance Program	NCA-3260
8	Subsection NF requires the Certificate Holder to certify, by application of appropriate Code Symbol and completion of the appropriate Data Report in accordance with NCA-8000, that the materials used comply with all requirements of NF-2000 and that the fabrication and installation complies with the requirements of NF-4000.	The package will be procured, identified, controlled, and manufactured in accordance with the J.L. Shepherd & Associates 10 CFR Part 71 Quality Assurance Program based on NQA-1, USNRC Regulatory Guide 7.10, and NUREG/CR 6407 Criteria. Therefore, Code Symbol stamping will not be applied to the fabrication and installation of package components.	NCA-1281 NCA-3800 NCA-8000 NF-4121
9	The ASME BPVC requires the use of an Authorized Inspection Agency (AIA) to provide inspection and audit services during the fabrication of components and supports.	The activities associated with the AIA, including those of the Authorized Nuclear Inspector (ANI), will be replaced by the auditing and inspection activities associated with the J.L. Shepherd & Associates 10 CFR Part 71 Quality Assurance Program, which will perform oversight activities during any procurement, identification, fabrication, assembly of components and final inspection activities of the BU650B package.	NCA-5000 NCA-8000 NF-4121
10	Materials for supports shall conform to the requirements of the specifications for materials listed in the tables of Section II, Part D, applicable to the Class of construction.	See Item 2.	NF-2121
11	Only those welding process which are capable of producing welds in accordance with the welding procedure qualification requirements of ASME BPVC, Section IX and this Subsection shall be used for welding support material or attachments thereto.	As permitted by USNRC NUREG/CR-3019 via NUREG/CR-1609, welding criteria of ASME BPVC, Section VIII, Division 1, may also be used for non-containment, structural welding.	NF-4311

Table 2-4B

BU650B ASME Boiler and Pressure Vessel Code, Section III, Division III Requirement Compliance Summary

Item	ASME BPVC or Requirement Issue	Alternative Compliance Basis	ASME BPVC Sections
1	ASME BPVC Section III, Division 3, uses the following terminology that is not consistent with the terminology used for this BU650B package:	The equivalent terminology and compliance basis used for the BU650B package are as follows :	Throughout Subsections WA and WB
	(a) "N3 Certificate Holder"	(a) J.L. Shepherd & Associates has the responsibility of the N3 Certificate Holder, with the exceptions noted.	
	(b) "Packaging Owner"	(b) J.L. Shepherd & Associates has the responsibility of the Packaging Owner, with the exceptions noted.	
	(c) "Design Specification"	(c) The information typically contained in an ASME BPVC Design Specification will be included in the BU650B Transportation Package Safety Analysis Report to be submitted to the USNRC for review and approval.	
	(d) "Design Report"	(d) The information typically contained in an ASME BPVC Design Report will be included in the BU650B package SAR.	
	(e) "Fabrication Specification"	(e) Replaced by J.L. Shepherd & Associates Fabrication, Assembly, and Inspection Records, Procurement Instructions Quality Category Assessments and Procurement Drawing documentation.	
	(f) "Certificate of Authorization"	(f) Replaced by USNRC-issued Certificate of Compliance	
2	The ASME BPVC Edition and Addenda dates shall be established in the Design Specification	The ASME BPVC Edition and Addenda to be used for the design and fabrication of the package shall be the 2001 Edition with Addenda through 2003.	WA-1140(a)

3	ASME BPVC, Section III, Division 3, requires that the N3 Certificate Holder use a NPT Certificate Holder to construct the containment system. The following ASME BPVC requirements apply to the NPT Certificate Holder.	A NPT Certificate Holder is not required to construct the containment system (i.e., package assembly) of the BU650B package. The primary containment system of the package is a sealed source; the shielded liner is considered as secondary containment.	WA-3420
	(a) The NPT Certificate Holder shall construct the containment system under the provisions of a Quality Assurance (QA) program that has been accepted by the Society. The QA program shall meet the requirements of the latest Division 3 Edition and Addenda issued at the time the containment system is constructed.	(a) The package will be procured, identified, controlled, and manufactured in accordance with the USNRC-approved, J.L. Shepherd & Associates Quality Assurance Program, issued under 10CFR Part 71, and based upon NQA-1, USNRC REGUIDE 7.10, and NUREG/CR-6407.	WA-1140(b) WA-3111 WA-3113 WA-3420(e)
	(b) The NPT Certificate Holder shall obtain an N-type Certification of Authorization and apply a Code Symbol Stamp to the completed containment system of the transportation packaging.	(b) Not required based upon item 3 above. The primary containment of the BU650B package is a sealed source as defined in 49 CFR 173.469. Secondary and tertiary containment are found in the Shielded Liner and packaging closure mechanism respectively.	WA-3351.4 WA-3356 WA-3361.3
4	The ASME BPVC requires that the Design Specification, Design Report, and Fabrication Specification be certified by one or more Registered Professional Engineers, competent in the applicable field of construction and related transport packaging requirements of ANSI/ASME N626.3.	The design and fabrication documents for the package shall be prepared and verified by personnel qualified in accordance with the USNRC-approved J.L. Shepherd & Associates QA Program.	WA-3351.4 WA-3356 WA-3361.3
5	The ASME BPVC requires the use of an Authorized Inspection Agency (AIA) to provide inspection and audit services during the construction and installation of the "containment" system. Other requirements related to the use of an AIA are as follows:	The activities associated with the Authorized Inspection Agency, including the Authorized Nuclear Inspector, will be replaced with auditing and inspection activities of the QA/QC organization performing the fabrication with oversight by the Design Owner, J.L. Shepherd & Associates.	WA-5000 WB-6113
	(a) The N3 and NPT Certificate Holder shall obtain written agreement with an AIA to provide inspection and audit services prior to application.	(a) The agreement with an AIA is replaced with auditing and inspection activities of the QA/QC organization performing the fabrication with oversight by the Design Owner, J.L. Shepherd &	WA-3320(o) WA-3420(h) WA-8130

		Associates.	
	(b) The N3 and NPT Certificate Holder shall file copies of the QA Manual with the AIA.	(b) The QA Program Plan of the Design Owner, J.L. Shepherd & Associates is filed with and approved by the USNRC (See Docket #71-0122).	WA-3373 WA-3461
6	The containment system shall be designed to account for buckling due to compressive stresses. However, the rules for evaluating buckling are under development.	The primary containment system is the radioactive sealed source manufactured under 49CFR173.469. The secondary and tertiary containment systems	WB-3211(c) WB-3133
7	Stress Limits for Bolts	Closure bolts for both the Shielded Liner and package assembly are evaluated in accordance with the guidance and design criteria provided in NUREG/CR-6007.	WB-3230

2.2 Materials

2.2.1 Material Properties and Specifications

The specifications for the BU650B package materials of construction are summarized in Table 2-5. The mechanical properties of the BU650B package materials that are used in the structural evaluation are described in this section. The material properties for all components of the packaging are described in Section 2.2.1.1. through Section 2.2.1.3, which include the crush strength properties of the Impact Limiter foam and Kaolite thermal barrier materials. The material properties of other materials considered in the structural evaluation are described in Section 2.2.1.4.

2.2.1.1 Structural Materials

The structural components of the BU650B package are fabricated from stainless steel materials. Grade 304 and/or grade 316 austenitic stainless steel, in either bar (SA-479/A479) or plate (SA-240/A240) form, is used to fabricate the structural components of the Lower Package Assembly, Lid Assembly, Closing Ring, and Impact Limiters. The BU650B package closure bolts are fabricated from 316 Stainless Steel. The structural evaluation of the BU650B is performed using mechanical properties of materials that are appropriate for the anticipated service conditions. The temperature range of interest for NCT is: -40°C to 93°C. A mass density of 8,030 kg/m3 and a Poisson's ratio of 0.3 are used for all stainless steel materials. Temperature-dependent mechanical properties for the structural material of the package, including design stress intensity (Sm), yield strength (Sy), tensile strength (Su), modulus of elasticity (E), and mean coefficient of thermal expansion (α), are obtained from the ASME BPVC, Section II, Part D and summarized in Table 2-5 through Table 2-8. The mechanical properties of grade 304 stainless steel material are summarized in Table 2-5. Since the package's structural components are fabricated using grade 304 stainless steel material, the structural evaluation of the BU650B is performed using the most conservative mechanical properties of this material for the condition being analyzed. The allowable stresses that depend on the yield and/or ultimate strength of grade 304 stainless steel at 93°C are calculated based on the lower strength values.

Elastic-plastic true stress-strain properties are used for package shell stainless steel material in the structural evaluation of the package for NCT free drop, HAC free drop, and HAC puncture tests. The stainless steel materials that form the package shells are modeled using a piecewise linear plasticity model. The data points on the true stress-strain curves are developed using the Ramberg-Osgood relationship as follows:

$$\frac{\varepsilon}{\varepsilon_o} = \frac{\sigma}{\sigma_o} + \alpha\left(\frac{\sigma}{\sigma_o}\right)n$$

where;

ε = true strain

σ = true stress

$\varepsilon_0 = S_y/E$, True yield strain

$\sigma_0 = S_y$, true yield stress

S_y = Yield Strength

E = Elastic Modulus

$$\alpha = \left[\frac{1n(1+e_u)}{1n[1+S_Y/E]} - \frac{S_u(1+e_u)}{S_Y(1+S_Y/E)}\right]\left[\frac{S_u(1+e_u)}{S_Y(1+\frac{S_Y}{E})}\right]^{-n}$$

S_u = Ultimate tensile strength

e_u = Ultimate strain

$n = 1/[l_n(1+e_u)]$

Using this relationship, and the material properties from Table 2-5 the upper-bound and lower-bound true stress-strain tables are developed for all of the BU650B package shell stainless steel materials over the temperature range of interest (-20°F to 200°F). The resulting stress-strain values are shown in Table 2-10A and 2-10B along with enveloping upper-bound and lower-bound stress-strain tables used for the package NCT and HAC free drop structural analyses. The enveloping upper-bound and lower-bound true stress-strain design data used for the BU650B package stainless steel shells in the 30' drop are summarized in Table 2-9. The lower-bound value is developed based on the minimum yield and ultimate strength values from Table 2-5 at an upper-bound temperature of 93°C and the lowest maximum elongation for all product forms and material types permitted for fabrication of the BU650B package shell components. However, the upper-bound value is based on a yield strength of 310 MPa and a tensile strength of 655 MPa since the values given in Table 2-5 represent the minimum expected values at temperature. In addition, the upper-bound value is conservatively extended beyond the failure strain of the BU650B package shell materials to a maximum strain of approximately 60%. This is done to avoid material failure that may lead to non-conservative predictions of the upper-bound drop loads.

The structural evaluation of the BU650B package for the HAC free drop and HAC puncture tests is performed using a plastic kinematic material model for the BU650B package closure bolts. The material model is defined by an elastic modulus, yield stress, tangent slope and failure strain. The tangent modulus (E_t) is calculated based upon the yield stress (S_y), yield strain (ε_y), ultimate tensile stress (S_u), and failure strain (ε_u) as follows:

$$E_t = \frac{S_u - S_y}{\varepsilon_u - \varepsilon_y}$$

Where:

$\varepsilon_y = (S_y/E)+0.002$

S_y = Yield Stress (0.2% offset)

E = Elastic Modulus

The upper-bound and lower-bound plastic-kinematic material properties for the BU650B package closure bolt material used for the structural evaluation of the BU650B package for the HAC free drop and HAC puncture tests are summarized in Tables 2.10A and 2.10B

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Table 2-5

Material Properties

Material	Poisson's Ratio	Mass Density (lb-sec^2/in^4)	Material Density (lb/in^3)	Young's Modulus (psi)	Strength Coefficient (*K*) (psi)	Hardening Exponent (*m*)
304 Stainless Steel	0.29	7.5130E-4	0.29	2.81E7	162,738	0.27208
316 Stainless Steel	0.29	7.5130E-4	0.29	2.8E7	135,156	0.22634
AISI 1010 Carbon Steel	0.29	7.3316E-4	0.283	3.0E7	77,364	0.18572
AISI 1020 Carbon Steel	0.29	7.3573D-4	0.284	3.0E7	156,749	0.1244
Lead	Bulk Modulus '(*K*)' (psi) 4.206E6	1.0645E-3	0.4109	Shear Modulus 7.2519E5	Yield Stress (psi) 1,740.45	Plastic Hardening Modulus (psi) 8,702.26
Kaolite 1600	0.01	3.3583E-05	Shear Modulus (Uncompressed) (psi) 7,405	1.0E6	Fully Compacted Yield Stress (psi) 40,000	Elastic Modulus (Uncompressed) (psi) 14,822
General Plastics Elast-A-Foam FR3712	0.01	1.797E-05	Shear Modulus (Uncompressed) (psi) for E_{ccu} 13,889 Shear Modulus (Uncompressed) (psi) for G_{abu} and G_{bcu} 3629 Shear Modulus (Uncompressed) (psi) for G_{abu} and G_{bcu} 3760	6.0E5	Fully Compacted Yield Stress (psi) 10,000	Elastic Modulus (Uncompressed) (psi) for E_{aau} and E_{bbu} 12,339

Table 2-6

Mechanical Properties of Type Grade 304 Stainless Steel

Temp. (°C)	Design Stress Intensity, S_m(2) (MPa)	Yield Strength, S_y(3) (MPa)	Tensile Strength, S_u(4) (MPa)	Modulus of Elasticity, E(5) (MPa X 10^3)	Mean Coef. Of Thermal Expansion, α(6) (m/m/°Cx10^{-6})
-40	138	207	517	*199*	*14.7*
-29	138	207	517	*198*	*14.8*
21	138	207	517	195	15.3
38	138	207	517	*194*	15.5
93	138	207	517	190	16.0

Notes:
1. Values for SA-240/A240 and SA-479/A479 product specifications.
2. ASME BPVC, Section II, Part D [2.11], Table 2A.
3. ASME BPVC, Section II, Part D [2.11], Table Y-1.
4. ASME BPVC, Section II, Part D [2.11], Table U.
5. ASME BPVC, Section II, Part D [2.11], Table TM-1, Material Group G.
6. ASME BPVC, Section II, Part D [2.11], Table TE-1, Group 3, Coefficient B (mean from 70°F).
7. Values shown in *italics* are calculated using linear interpolation or linear extrapolation.

Table 2-7

Mechanical Properties of Type 316 Stainless Steel

Temp. (°C)	Design Stress Intensity, S_m(2) (MPa)	Yield Strength, S_y (3) (MPa)	Tensile Strength, S_u (4) (MPa)	Modulus of Elasticity, E(5) (MPa X 10^3)	Mean Coef. Of Thermal Expansion, α(6) (m/m/°C x 10^{-6})
-40	138	207	517	*199*	*14.7*
-29	138	207	517	*198*	*14.8*
21	138	207	517	195	15.3
38	138	207	517	*194*	15.5
93	138	179	517	190	16.0

Notes:
1. Values for SA-240/A240 and SA-479/A479 product specifications.
2. ASME BPVC, Section II, Part D [2.11], Table 2A.
3. ASME BPVC, Section II, Part D [2.11], Table Y-1.
4. ASME BPVC, Section II, Part D [2.11], Table U.
5. ASME BPVC, Section II, Part D [2.11], Table TM-1, Material Group G.
6. ASME BPVC, Section II, Part D [2.11], Table TE-1, Group 3, Coefficient B (mean from 70°F).
7. Values shown in *italics* are calculated using linear interpolation or linear extrapolation.

Table 2-8

Mechanical Properties of A240, Type XM-19 Stainless Steel

Temp. (°C)	**Design Stress Intensity, S_{m}(2) (MPa)**	**Yield Strength, S_{y} (3) (MPa)**	**Tensile Strength, S_{u} (4) (MPa)**	**Modulus of Elasticity, E(5) (MPa X 10^3)**	**Mean Coef. Of Thermal Expansion, α(6) (m/m/°C x 10^{-6})**
-40	230	379	690	199	14.3
-29	230	379	690	198	14.4
21	230	379	690	195	14.8
38	230	379	690	194	14.8
66	229	343	688	192	15.1
93	228	325	685	190	15.3

Notes:
1. ASME BPVC, Section II, Part D [2.11], Table 2A.
2. ASME BPVC, Section II, Part D [2.11], Table Y-1.
3. ASME BPVC, Section II, Part D [2.11], Table U.
4. ASME BPVC, Section II, Part D [2.11], Table TM-1, Material Group G.
5. ASME BPVC, Section II, Part D [2.11], Table TE-1, Group 4, Coefficient B (mean from 70°F).
6. Values shown in *italics* are calculated using linear interpolation or linear extrapolation.

Table 2-9

Grade 304 Stainless Steel True Stress-Strain Design Data

Lower-Bound Curve		Upper Bound Curve	
True Strain	**True Stress (Pa)**	**True Strain**	**True Stress (Pa)**
0.00055	5.99E+07	0.00049	8.81E+07
0.00250	1.20E+08	0.00153	1.76E+08
0.00718	1.80E+08	0.00434	2.64E+08
0.01593	2.39E+08	0.01077	3.52E+08
0.03004	2.99E+08	0.02328	4.40E+08
0.05083	3.59E08	0.04485	5.28E+08
0.07959	4.19E+08	0.07901	6.17E+08
0.11781	4.79E+08	0.12982	7.05E+08
0.16616	5.39E+08	0.30000	8.81E+08
0.3000	6.59E+08	0.42991	9.69E+08
----	----	0.59749	1.06E+09

Notes:

1. Lower-bound data calculated based on the lowest yield and ultimate strength of all package shell stainless steel materials at an upper-bound temperature of 93°C and an ultimate strain of 40%. The stress-strain data is terminated at a strain of 30%, equal to the lowest maximum elongation for all product forms and material types permitted for the fabrication of the package shell assembly components.
2. Upper-bound data based on an upper-bound yield strength 310 MPa, an upper-bound ultimate strength of 655 MPa, and an ultimate strain of 30%. The upper-bound stress-strain data is extended to a strain of approximately 60% to avoid material failure that may lead to non-conservative predictions of the upper-bound drop loads.

Table 2-10A
Component Maximum Plastic Strains (%); Top through the 45 degree Impacts

Part #	Part Identification	Top	5 deg	10 deg	15 deg	20 deg	25 deg	30 deg	35 deg	40 deg	45 deg
1	Cask Body Outer Btm Plate	0.89	4.71	5.03	2.33	2.12	1.88	1.69	1.09	3.81	4.41
2	Cask Body Inside Btm Plate	0.49	0.32	0.60	0.82	0.93	1.10	1.14	1.24	1.26	1.16
3	Cask Body Btm Plate Lip	0.37	0.18	0.33	0.43	0.55	0.59	0.61	0.68	0.71	0.51
4	Cask Body Outer Cylinder	0.63	1.46	0.59	0.63	0.70	0.86	1.02	1.13	1.07	1.05
5	Cask Body Inside Cylinder	0.10	1.00	1.22	1.37	1.46	1.55	1.55	1.80	1.99	2.37
6	Cask Body Top Closure Ring	2.88	3.81	8.00	14.47	23.40	30.14	31.08	36.04	33.16	50.63
8	Cask Body Welded Nut	0.86	13.48	13.24	17.79	13.04	19.10	18.82	17.37	24.20	3.82
10	**Cask Outer Bolt**	7.74	10.00	14.56	**16.53**	13.17	11.15	9.96	9.38	9.07	6.71
12	Cask Body Washers	0.38	0.41	1.08	0.96	0.88	0.59	0.49	0.40	0.41	0.40
25	Cask Lid Bolting Plate	4.34	4.42	4.62	4.11	5.68	5.39	5.79	5.80	5.77	6.21
26	Cask Lid Mid Plate	1.76	2.91	2.15	1.28	1.04	0.95	0.87	0.83	0.80	0.70
27	Cask Lid Out Cyl	9.03	12.66	12.25	10.83	9.86	8.19	8.01	8.32	8.17	8.47
28	Cask Lid Ins Cyl	8.39	7.59	5.83	4.24	2.29	1.53	1.47	1.31	1.32	1.16
29	Cask Lid Top Plate	9.96	10.21	13.20	9.94	9.07	7.36	7.42	10.78	11.26	12.43
30	Cask Lid Out Cyl w/Weld	47.28	77.70	85.21	75.64	63.02	53.69	54.32	58.45	73.03	52.54
31	Cask Lid Ins Plate	27.10	27.00	22.54	16.11	11.75	10.39	9.29	8.96	8.82	9.22
32	Cask Lid Ins Cyl w/Weld	30.49	30.06	26.09	21.06	15.42	12.00	8.94	11.17	10.40	12.49
33	Inside Shoring	54.40	53.44	35.46	26.87	33.90	28.22	25.69	25.53	24.90	27.28
57	Impact Limiter Inner Angle	19.29	30.99	30.96	26.58	28.78	26.69	26.60	27.58	28.28	29.27
70	Lifting Ring; Impact Limiter	6.74	16.87	20.11	11.13	11.65	10.93	10.13	14.87	15.66	19.49
72	Bolting Lug; Impact Limiter	27.28	24.71	38.18	63.98	62.37	62.39	59.62	58.42	60.56	64.56
73	Pins; Cask Body / Impact Limiter	9.42	10.19	17.28	37.28	90.67	115.10	138.27	132.80	126.50	56.90
100	Shield Liner Lid Closure Shell	52.03	53.03	41.10	44.12	38.03	37.93	34.69	30.63	28.54	21.44
104	Shield Liner Lid Lead	2.21	2.33	1.46	0.90	0.64	0.80	0.81	1.09	1.23	1.65
105	Shield Liner Content	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	**Shield Liner Bolts**	7.20	3.71	2.32	1.91	1.25	2.67	3.80	6.34	**9.19**	4.80
109	Shield Liner Washers	1.10	0.55	0.11	0.07	0.00	0.92	0.35	0.81	1.32	1.86
112	4x4 Mounting Bracket; Cask Body	2.42	3.50	3.28	5.61	5.71	5.90	6.15	6.21	5.99	5.50
113	Mounting Bracket Lug; Cask Body	20.46	28.21	37.82	51.24	50.24	47.64	56.64	56.41	57.92	62.68
114	Mounting Brackets Welds	3.10	6.01	10.00	5.92	6.10	5.71	6.00	7.87	8.41	8.87
119	**Cask Body Bolts Core**	7.63	8.89	13.48	**16.13**	12.89	10.85	9.54	8.96	8.68	6.16
121	**Shield Liner Bolts Core**	2.04	1.95	1.15	0.80	0.19	0.52	0.92	1.37	2.22	**2.76**
124	Impact Plate on Shield Liner	28.88	115.56	48.34	36.34	50.49	43.57	39.52	37.67	43.90	35.12

From Section 2.12.4. DAC-P09YCW01-0001 000 00

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Table 2-10B

Component Maximum Plastic Strains (%); 50 through 90 degree Impacts

Part #	Part Identification	50 deg	55 deg	60 deg	65 deg	70 deg	75 deg	80 deg	85 deg	Side
1	Cask Body Outer Btm Plate	0.62	0.44	2.69	0.53	5.84	6.44	1.90	1.66	5.65
2	Cask Body Inside Btm Plate	1.36	1.30	2.07	2.86	5.29	5.30	5.77	4.42	8.61
3	Cask Body Btm Plate Lip	0.75	0.72	1.65	2.43	3.16	3.29	3.65	2.48	5.29
4	Cask Body Outer Cylinder	0.96	0.85	1.21	0.95	3.11	3.06	5.86	5.22	2.15
5	Cask Body Inside Cylinder	1.99	2.00	1.94	1.50	2.83	2.33	2.68	2.80	3.65
6	Cask Body Top Closure Ring	25.14	8.96	1.92	1.15	3.04	4.21	4.41	5.21	5.72
8	Cask Body Welded Nut	16.19	29.15	13.60	12.88	17.27	15.42	13.71	18.53	11.47
10	**Cask Outer Bolt**	7.37	6.29	4.19	4.09	4.55	6.24	6.80	9.23	8.73
12	Cask Body Washers	0.35	0.30	0.16	0.10	0.37	0.98	0.41	1.36	0.44
25	Cask Lid Bolting Plate	4.81	2.76	2.66	3.39	3.46	3.25	2.09	2.97	3.91
26	Cask Lid Mid Plate	0.67	0.67	0.52	0.43	0.36	0.24	0.25	0.33	0.26
27	Cask Lid Out Cyl	7.80	7.95	6.75	2.81	1.63	2.44	1.25	1.48	0.99
28	Cask Lid Ins Cyl	0.83	0.78	0.41	0.28	0.24	0.23	0.29	0.34	0.44
29	Cask Lid Top Plate	13.83	14.46	16.86	16.24	17.23	17.94	15.96	16.45	13.33
30	Cask Lid Out Cyl w/Weld	51.68	52.87	90.66	31.16	13.77	15.79	3.85	6.39	3.14
31	Cask Lid Ins Plate	6.73	6.54	4.53	3.52	6.58	2.34	2.35	3.08	3.55
32	Cask Lid Ins Cyl w/Weld	9.63	9.19	4.91	4.00	3.53	2.93	3.18	4.09	3.16
33	Inside Shoring	25.70	24.57	22.65	20.36	16.73	13.78	13.77	12.18	10.88
57	Impact Limiter Inner Angle	24.59	25.06	31.32	27.69	41.85	26.09	46.03	34.83	19.57
70	Lifting Ring; Impact Limiter	20.32	21.56	27.47	26.95	27.47	29.23	26.65	27.65	27.70
72	Bolting Lug; Impact Limiter	61.45	62.80	61.53	24.53	32.00	24.55	21.08	25.95	14.49
73	Pins; Cask Body / Impact Limiter	101.34	55.86	34.61	10.76	17.48	10.69	10.89	12.79	7.81
100	Shield Liner Lid Closure Shell	26.17	27.59	14.00	13.32	17.91	15.46	4.71	7.95	14.60
104	Shield Liner Lid Lead	1.13	1.06	0.51	0.27	0.40	0.18	0.14	0.41	0.73
105	Shield Liner Content	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	**Shield Liner Bolts**	3.86	3.52	0.73	0.68	2.53	1.19	1.23	1.77	2.41
109	Shield Liner Washers	1.34	1.42	0.45	0.00	0.22	0.00	0.00	0.00	0.00
112	4x4 Mounting Bracket; Cask Body	5.81	5.50	5.19	2.72	3.26	3.74	3.26	4.19	4.20
113	Mounting Bracket Lug; Cask Body	56.06	49.76	47.75	21.40	15.91	23.13	15.34	23.19	14.26
114	Mounting Brackets Welds	10.46	11.28	20.37	18.87	23.10	27.14	21.44	24.45	23.62
119	**Cask Body Bolts Core**	6.96	5.93	4.15	4.03	4.30	5.75	5.97	7.60	8.19
121	**Shield Liner Bolts Core**	2.02	1.82	0.26	0.12	1.86	0.77	0.83	1.17	1.69
124	Impact Plate on Shield Liner	27.83	28.76	47.16	26.27	19.41	18.51	18.12	27.69	4.66

From Section 2.12.4. DAC-P09YCW01-0001 000 00

2.2.1.2 Shielding Material

The BU650B package does not contain primary shielding. Shielding is provided by a separate shielded liner, manufactured in accordance with 49 CFR 173.469. Shielded Liners contain lead or lead-equivalent shielding materials as primary shielding. Shielding required for radioactive content loading is identified in Table 5-5.

2.2.1.3 Impact Limiter Foam

The Impact Limiter assemblies are filled with rigid, closed-cell product manufactured by General Plastics of Seattle Washington and is known as "LAST-A-FOAM® FR-3712" - a polyurethane foam having a nominal density of 12.0 per cubic foot (216 kg/m3). (See Table 2-7 for material properties). The polyurethane foam is installed in-situ in the Impact Limiter shells, with foam rise parallel to the longitudinal axis of the package. The nominal static crush strength data of the polyurethane foam at room temperature, both parallel and perpendicular to the direction of foam rise, are summarized in Tables 2-12A and 2-12B. The dynamic stress versus strain curves for the polyurethane foam material, which are used for the NCT and HAC free drop test evaluations, are developed based on data provided by the foam manufacturer. Upper-bound and lower-bound dynamic stress versus strain curves are developed considering the effects of crush direction, i.e., parallel or perpendicular to the direction of foam rise; temperature; strain rate; and tolerance on foam crush strength. The minimum and maximum foam temperatures considered are -20°F and 260°F, respectively. These temperatures bound the range of temperatures that the foam will experience under all initial conditions for the NCT and HAC free drop tests. The dynamic crush strength (σDynamic) of foam is proportional to the static crush strength (σStatic) and is predicted by the following equations:

$$\sigma\text{Dynamic} = (\text{YInt})(\sigma\text{Static})\text{S}$$

Where YInt and S are the dynamic crush strength regression coefficients provided by the foam manufacturer. The static crush strength of foam at the lower- and upper-bound temperatures of -20°F and 260°F are calculated based on temperature correlation factors (CT) provided by the foam manufacturer. The average static compressive strength of the polyurethane foam at room temperature is required to be within ±10% of the nominal value for crushing parallel and perpendicular to the direction of foam rise. Therefore, the maximum and minimum static crush strengths at each strain value are taken as 110% and 90% of the nominal crush strength value. The dynamic crush strength versus strain data for foam temperatures of -20°F and 260°F are summarized in Table 2-13. The data shows that the dynamic crush strength of polyurethane foam parallel to the direction of foam rise is slightly higher than the perpendicular to rise dynamic crush strength in all cases. For design purposes, upper-bound and lower-bound dynamic stress versus strain curves are developed and used for all drop analyses, regardless of crush orientation.

The bounding design dynamic crush strength data is summarized in Table 2-13 along with the maximum and minimum dynamic crush strength values at temperature.

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Table 2-11

General Plastics Last-A-Foam FR3712, Rigid Polyurethane Foam

Property	English	Metric	Test Method
Density (pcf) (kg/m^3)	12.0	192	ASTM D-1622
Compressive Strength (psi)(kPa)			ASTM D-1621
Parallel to Rise			
@ -65°F	757	5219	
@ 75°F	487	3355	
@ 200°F	289	1991	
@ 250°F	190	1307	
Perpendicular to Rise			ASTM D-1621
@ -65°F	732	5050	
@ 75°F	457	3154	
@ 200°F	284	1961	
@ 250°F	194	1340	
Compressive Modulus (psi)(kPa)			ASTM D-1621
Parallel to Rise			
@ - 65°F	15,227	104,993	
@ 75°F	13,889	95,762	
@ 200°F	10,032	69,172	
@ 250°F	7,719	53,223	
Perpendicular to Rise			ASTM D-1621
@ - 65°F	14,872	102,542	
@ 75°F	12,339	85,080	
@ 200°F	9,092	62,691	
@ 250°F	7,719	53,223	
Tensile Strength (psi) (kPa)			
Parallel to Rise	424	2,926	ASTM 1623 Type A Specimens
Perpendicular to Rise	417	2,876	
Shear Strength (psi) (kPa)			
Rise Parallel to Specimen Width	338	2,329	ASTM C-273 Compression Shear
Rise Parallel to Specimen Thickness	329	2,271	
Tensile Modulus (psi) (kPa)			
Parallel to Rise	15,599	107,556	ASTM 1623 Type A Specimens
Perpendicular to Rise	16,336	112,639	
Shear Modulus (psi) (kPa)			
Rise Parallel to Specimen Width	3,629	25,020	ASTM C-273 Compression Shear
Rise Parallel to Specimen Thickness	3,760	25,927	
Flexural Strength (psi) (kPa)			
Rise Parallel to Test Span	599	4,128	ASTM D-790, Method 1-A
Rise Parallel to Beam Thickness	572	3,947	
Flexural Modulus (psi) (kPa)			
Rise Parallel to Test Span	17,947	123,743	ASTM D-790, Method 1-A
Rise Parallel to Beam Thickness	13,986	96,435	

From: General Plastic Manufacturing Co., Tacoma, Washington 4/7/2004

Table 2-12A

Static Nominal Crush Strength, Parallel to Direction of Rise 11-40lb$_m$/ft^3

Temp	Correlation Factor	10%	20%	30%	40%	50%	60%	65%	70%
-20°F	C_T	1.35	1.33	1.32	1.31	1.31	1.30	1.28	1.26
75°F	Y_{INT}	4.3422	3.8755	3.5241	3.0307	3.0402	3.4889	5.8935	5.6055
	S	1.8809	1.9321	1.9872	2.0755	2.1451	2.2143	2.1041	2.2368
100°F	C_T	0.86	0.87	0.88	0.88	0.89	0.90	0.90	0.97
140°F	C_T	0.72	0.74	0.75	0.75	0.75	0.76	0.76	0.81
180°F	C_T	0.62	0.63	0.65	0.65	0.65	0.65	0.64	0.68
220°F	C_T	0.56	0.56	0.57	0.57	0.56	0.54	0.54	0.57
260°F	C_T	0.40	0.40	0.41	0.42	0.41	0.43	0.43	0.47

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Table 2-12B

Static Nominal Crush Strength, Perpendicular to Direction of Rise 11-40lb_m/ft^3

Temp	Correlation Factor	10%	20%	30%	40%	50%	60%	65%	70%
-20°F	C_T	1.34	1.33	1.32	1.33	1.30	1.28	1.24	1.17
75°F	Y_{INT}	4.1342	3.5581	3.2664	2.8352	2.8988	3.3972	6.5439	5.6464
	S	1.8957	1.9593	2.0109	2.0955	2.1602	2.2242	2.0660	2.2321
100°F	C_T	0.84	0.85	0.86	0.88	0.87	0.88	0.88	0.90
140°F	C_T	0.72	0.73	0.74	0.76	0.75	0.76	0.76	0.79
180°F	C_T	0.62	0.63	0.64	0.65	0.65	0.65	0.65	0.67
220°F	C_T	0.53	0.53	0.54	0.55	0.54	0.54	0.54	0.56
260°F	C_T	0.39	0.39	0.40	0.41	0.41	0.40	0.40	0.42

Table 2-13

Static to Dynamic Crush Strength Adjustment, GP Last-A-Foam, FR3712

Strain	10%	20%	30%	40%	50%	60%	65%	70%
Y_{INT}	1.2971	1.4397	1.5181	1.3887	1.4419	1.4275	1.3871	1.4660
S	1.0330	1.0069	0.9941	1.0028	0.9912	0.9831	0.9910	0.9586

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2.2.1.4 Kaolite 1600 Thermal Barrier Material

The Thermal Ceramics Product, Kaolite 1600 is a castable insulator which provides low thermal conductivity value, ease of installation and superior performance, particularly in petrochemical applications. Kaolite 1600, as used in the BU650B Radioactive Materials Transportation Package, is vibra-cast, then dried for a minimum of 24 hours at 220°F, and then fired at 1500°F for a period of 5 hours which provides the maximum capabilities of the material as identified in Table 2-14.

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Table 2-14

Manufacturer Defined Material Properties, Kaolite 1600

	Kaolite 1600	
	cast	gunned
Recommended Method of Application, X[1]		
Cast	x	-
Gunned	-	x
Avg. lbs req to place 1 Cubic Ft[2]	23	36
Recommended Water, %[3]		
Casting by Vibrating	120-145	-
Pouring	150-180	-
Recommended Temp Use Limit, °F	1600	1600
Melting Point, °F	2300	2300
Density, pcf		
Dried @ 220°F	-	-
Fired @ 1500°F	-	-
Fired @ Temperature Use Limit	20-25	31-39
Modulus of Rupture, psi (ASTM C 133)		
dried 18-24 hours @ 220°F	45-75	70-120
fired 5 hrs. @ 1500°F	25-40	35-55
fired 5 hrs. @ temperature use limit	25-40	35-50
dried 18-24 hours @ 220°F	80-120	125 – 175
Fired 5 hrs @ 1500°F	50-70	90-120
Fred 5 hrs @ temperature use limit	50-70	90-120
Permanent Linear Change, %, (ASTM C 133)[4]		
dried 18-24 hours @ 220°F	-	-
fired 5 hrs @ 1500°F	-1.0 to -2.0	-1.0 to -2.0
fired 5 hrs @ temperature use limit	-1.5 to -2.5	-1.5 to -2.5
Chemical Analysis, %, Weight Basis After Firing[5]		
Alumaina, Al_2O_2	11	11
Silica, SiO_2	33	33
Ferric oxide, Fe_2O_2	7.9	7.9
Titanium oxide, TiO_2	1.4	1.4
Calcium oxide, CaO	30	30
Magnesium oxide, MgO	12.1	12.1
Akalies, Na_2O_2, K_2O	3.7	3.7
Thermal Conductivity, BTU· in/hr ·ft^2·°F, ASTM C 417		
mean temperature @ 500°F	0.87	1.23
@ 1000°F	1.02	1.11
@ 1500°F	1.16	1.20
@ 2000°F	-	-
Pounds per Bag	50	50

Table 2-14 Notes: (Taken from Thermal Ceramics Product Data).

[1.] Properties indicated are for vibratory cast materials only.
[2] Gunite installation may require 10 to 30% more material due to compaction and rebound loss.
[3] Water requirements indicated are offered as a guide. Actual water required may be subject to field conditions. Consult Thermal Ceramics sales representatives for assistance.
[4] Fired linear change values reflect samples taken from a dried to fired state.
[5] Chemical analysis % for CaO in parentheses indicates the percentage of reactive CaO present if less than the total. The balance is calcia from the anorhite aggregate.

2.2.2 Chemical, Galvanic, or Other Reactions

The BU650B package materials of construction are evaluated for possible chemical, galvanic, or other reactions considering the contact of dissimilar materials and the operating environments. Material interactions are considered, including galvanic corrosion, stress corrosion cracking, and eutectic formation. Eutectic formation is not considered as a result of using sealed sources in special form containing non-fissile materials. No significant interactions are found to occur that would affect package performance. Hydrogen generation by chemical and galvanic reactions does not occur within the package and therefore found not to affect package effectiveness. The payload does not generate hydrogen through radiolysis. Any hydrogen generation would occur as a result of condensation forming as a consequence of extreme temperature change which can only occur as a result of loading or unloading. Consequently, the package has no significant chemical, galvanic, or other reactions that affect package performance.

2.2.3 Effects of Radiation on Materials

The BU650B package is designed using materials that will withstand damaging effects from radiation. Durable materials of construction such as austenitic stainless steel, alloy steel, lead, and Kaolite 1600 insulating materials are unaffected (over the 20-year life cycle) by the radiation levels in this package and their resistance to radiation is therefore not addressed.

The polyurethane foam material used for the Impact Limiter cores is unaffected by gamma radiation exposure up to 2×10^8 rads, equivalent to 1,000 rads/hour for a period of 20 years. At radiation exposure up to 2×10^8 rads, testing shows no effect on density or crush strength, (Table 2-15, below). Furthermore, the resistance of the polyurethane foam material to water absorption is unaffected by radiation exposure up to 7×10^7 rads (Table 2-16).

Table 2-15

Effects of Radiation, FR 3712

Exposure	Density lbs./ft^3	Stress (psi) @ % Crush							
		10%	20%	30%	40%	50%	60%	65%	70%
Control	10.78	352	359	382	426	508	686	851	1121
2 x 10^7 rads	10.68	341	348	373	417	499	678	848	1137
4.2 x 10^7 rads	10.58	328	336	360	405	488	666	835	1122
7 x 10^7 rads	10.64	333	341	366	408	491	666	831	1106
2 x 10^8 rads	10.76	347	356	380	422	507	682	844	1112

Source: General Plastics Design Guide, FR 3700
Verified by: University of Michigan Phoenix Memorial Laboratory. Specimens irradiated in a Co-60 Irradiator to a maximum dose of 2x10^8 rads (gamma). Dosage represents approximately 40 years of life in a field of 500 rads per hour.
Average of five specimens at each dosage

Table 2-16

Water Absorption, General Plastics Last-A-Foam, FR3712

Time and Radiation Exposure	Density, lbs/ft^3	Before Submersion	After Submersion	Weight Gain (gr)	% Volume Gain
1-Day Immersion 7.0 x 10^7 rads	10.64	44.66	48.67	4.01	1.37
10-Day Immersion 7.0 x 10^7 rads	10.65	44.29	53.78	9.49	2.98
100- Day Immersion 7.0 x 10^7 rads	10.62	44.44	69.26	24.82	8.35

Source: General Plastics Design Guide, Last-A-Foam FR3700
Samples placed in water at 125°F and at pressure of 17.7psig (122 kPa).
Resistance to water is consistent with greater than 95% closed-cell content.

A nickel-based thread lubricant is specified for as-needed lubrication of threaded fasteners. This material is commonly used for nuclear applications and is suitable for use in radiation environments. None of the

BU650B package fasteners is located in high exposure areas, and the lubricant is frequently cleaned and replaced, so the lubricant is not subject to radiation damage.

2.3 Fabrication and Examination

2.3.1 Fabrication

All work performed to fabricate the BU650B package is performed under the J.L. Shepherd & Associates 10 CFR 71, Subpart H, Quality Assurance Program, NRC approval number 71-0122. The BU650B does not utilize a primary containment system. Secondary and tertiary containment systems are manufactured in accordance with the applicable requirements of 10 CFR Part 71, Subpart H. An NPT Certificate Holder and an Authorized Inspection Agency is not required for the construction of the BU650B package. The non-containment structural components of the package are fabricated in accordance with the applicable requirements of Subsection NF of the ASME BPVC for plate- and shell-type Class 2 supports. Standard industry practices are used for the fabrication of the gamma shield components, the BU650B Lower Package Assembly, Lid Assembly and Impact Limiters. Other non-containment structural components of the BU650B package are fabricated from ASTM materials that are equivalent to ASME materials, as permitted by NUREG/CR-3854. All BU650B package welds are, SFA-5.9 ER308L, or ER316L, or equivalent rated weld filler metal. All weld filler metal is required to have a minimum delta ferrite content of 5 FN. The quality category of the weld material is required be equal to or greater than the higher quality category of the components being joined. A certified material test report (CMTR) is provided for all materials, including weld filler metals, used to fabricate the BU650B package.

Consumables, bolts, washers, nuts, coupling nuts, and lifting eyes are procured from commercial suppliers and commercially dedicated in accordance with the requirements of the J.L. Shepherd & Associates QA Program, commensurate with their respective importance to safety using a graded approach. All materials, components, and assemblies used for the fabrication of the BU650B package, including the weld filler metal, are labeled to maintain control and traceability of materials throughout the fabrication process. Marking of materials, components, and assemblies is done using permanent methods that do not result in harmful contamination or sharp discontinuities, or infringement upon the minimum required material thickness. All operations associated with the fabrication and assembly of the BU650B package are included in written shop instructions, e.g., fabrication travelers and/or procedures. (See Section 8.3.2).

All welding is performed in accordance with a written welding procedure specification (WPS) that is qualified in accordance with the applicable requirements of the ASME BPVC. All personnel performing welding are qualified to use the welding procedure, and their qualifications are documented in accordance with the applicable requirements of the J.L. Shepherd & Associates Quality Assurance Program. Only SMAW (Arc and Heli-arc) and GMAW (TIG) welding processes are permitted for the fabrication of the package. Inspection requirements are stated in fabrication traveler documents, drawings, or procedures as appropriate.

The general processes used to fabricate each finished assembly of the package are described as follows:

Lower Package Assembly

The Lower Package Assembly consists of an inner and outer shell, joined on the bottom by an inner and outer bottom plate. The top of the inner and outer shell assemblies are joined by a bolting plate and lid assembly which complete the Lower Package Assembly.

The inner and outer shell bottoms are both fabricated by machining solid pieces of grade 304 stainless steel plate material. This minimizes the amount of welding and/or forming operations required to fabricate the package, which results in less weld distortion and residual stress. The Lower Package Assembly Inner and Outer Shells are fabricated from rolled, grade 304 stainless steel plate with a full-penetration longitudinal seam weld to form each cylinder. The use of a backing bar made from similar material is permitted for the longitudinal seam weld, provided that it is removed for the finished assembly. After completion, the Inner Bottom Plate is attached to the now-formed Inner Shell cylinder. Following completion of a series of machining operations, bolting anchors are installed in the bolting plate in accordance with the manufacturing instructions. The next step is to attach the Lower Package Assembly Inner Shell to the Closing Flange as indicated on drawing BU650B-LP-2. After attachment of the Inner Shell, the Outer Shell may then be attached as indicated. Once the Outer Shell is attached, the Lower Package Assembly is then ready to receive the Kaolite 1600 thermal barrier material. The Lower Package Assembly is then inverted and Kaolite 1600 is installed in the annular space between the inner and outer shell walls as a slurry. It is then dried and cured in-situ, in accordance with manufacturer's instructions. When complete, the Kaolite 1600 presents a thermal barrier material consisting largely of cement and vermiculite blend which will, in event of fracture, self-fill and prevent heat paths to the center of the package. After curing, the Outer Shell Bottom is attached using a fillet weld. Detailed instructions may be found at Section 8.3.2. Weight of the Lower Package Assembly is approximately 2,680 pounds, without the Lid Assembly.

Lid Assembly

The Lid Assembly is fabricated from grade 304 stainless steel plate and consists of a plate, ½" thick, with a top riser which extends two inches to provide protection for the closure bolts and a 4" bottom extension, constructed of ¼" thick stainless steel intended to house the Kaolite 1600 thermal barrier material. There are 24 each, 7/8" diameter holes equally spaced, chamfered and stress relieved on the lid circumference to accommodate package closure.

Impact Limiter Assembly

The Impact Limiter Assembly is fabricated from grade 304 stainless steel sheet (12 gage), stainless steel pipe, and foam. It is designed as a sacrificial, energy absorbing empennage whose main purpose is to collect the energies applied as a consequence of a fall or drop from a distance of 30'. As a consequence of the design the Impact Limiter Assemblies (top and bottom) effectively limit energy delivered to the package contents to a minimal amount. The Impact Limiter Assembly is attached to the package body (top and bottom) at four hard-mounted points, with pins and clips that facilitate attachment and removal. These attachment points are configured such that rotational energy delivered as a result of drop is effectively absorbed. This is accomplished by use of angle supports (8 each) within the interior of the Impact Limiter which are attached to the mid panel, and minor diameter wall, giving rigidity to the Impact Limiter while allowing the Impact Limiter to collapse when stressed. The principal energy-absorbing material contained within the Impact Limiter is polyurethane foam. The foam is manufactured by General Plastics of Seattle, Washington and is known as GP3712 polyurethane foam at a density of 12 (+/- 15%) pounds per cubic foot.

Shielded Liners: Shielded Liners are fabricated separately in accordance with the standards applied to a DOT 7A Package, as found in 49 CFR 173.462. The lead shielding material is cast into the shielded liner in such manner that there are no voids available to permit lead movement in the event of impact.

2.3.2 Examination

The manufacture of all BU650B sub-assemblies is controlled by specific work instruction known as "Fabrication, Manufacture, and Assembly Instruction" for the specific sub-assembly. These work instructions can be found in Section 2.12.5. Each work instruction defines the specific process used in the acquisition of raw materials, specifications for those materials, identification of those materials, dimensional preparation of materials, fabrication and/or welding of prepared materials, inspection process relative to each function, forms necessary for recording acceptance information and record retention of those items. All examinations are conducted under the guidance of the J.L. Shepherd & Associates Quality Assurance Program Implementing Procedures, QAM/QP 9.0; 10.0; and 11.0 where applicable tests are used. Should examination identify a non-conforming condition, provisions for re-work and re-examination are provided in those instructions.

2.4 General Requirements for All Packages

This section addresses the requirements of 10 CFR 71.43, "General Standards for All Packages" and identifies specifically how the BU650B complies with the requirements.

2.4.1 Minimum Package Size

10 CFR 71.43 specifies the smallest overall dimensional feature of the package cannot be less than 10cm (4 inches). The BU650B, as designed, has no dimensional features smaller than 4 inches. (See dimensional descriptions in Section 1.2.

2.4.2 Tamper-Indicating Feature

The BU650B closure mechanism consists of a lower package Closing Ring which is crowned with a Lid Assembly as defined in

Section 2.3.1 (Lid Assembly), above. After installation of 24 bolts and application of proper bolt pre-load, a tamper-proof seal is placed across the seam of the mating flanges. This seal is serialized. The numbers of each seal used are recorded on shipping and inspection documents. Should a seal be broken or pulled, an obvious visual indicator appears. BU650B Package Operating Instructions direct the operator to stop processing the package and immediately notify JLS&A shipping personnel should the seal reveal evidence of damage or tampering.

2.4.3 Positive Closure

The Closure Mechanism for the BU650B consists of installation of 24 bolts through a Closing Ring into anchors, fabricated specifically for the package. These bolts are then tightened to a specified torque level in order to prevent inadvertent loosening as a consequence of vibration during transport. Additionally, there is a 2" tall energy absorber fabricated onto the lid assembly which is designed to protect the bolt heads as they are installed. The closure also is covered by the Impact Limiter which must be removed in order to loosen or remove the bolts.

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices

There are no lifting devices attached to the BU650B designed to lift the entire package. The package is designed to be lifted, empty or loaded, from a pallet large enough to accommodate the diameter of the lower Impact Limiter. At the center of the lifting pallet is a post which supports the bottom of the package. Rails attached under the pallet support the post and provide a channel for lifting forks to pass when elevating or lowering the package from a conveyance.

At the top center of the Lid Assembly is a lifting ring, designed to lift the lid from the package. When the package is assembled with Impact Limiters attached, this lifting ring is not readily accessible for use, and is not visible unless directly observed from the top of the assembled package. This lifting ring is labeled with the words "For Removal of Lid Only". The lid lifting ring, as designed, is capable of lifting 7,500 pounds only. The lid assembly weighs approximately 360 pounds.

2.5.2 Tie-Down Devices

The BU650B package is designed for transport within a covered conveyance. As such it can be secured with blocking bars within the covered conveyance in a manner which would prohibit movement vertically and horizontally. If transported by flatbed conveyance, the package may be fitted with a specially designed "Spider Frame Assembly" which fits over the top Impact Limiter. This Spider Frame is intended to restrict the package from moving both vertically and horizontally. At the ends of the arms (4) are Hoist Rings having a rated load capacity of 15,000 pounds each. These Hoist Rings are made of forged and machined alloy steel.

Additionally, the lifting pallet upon which the package rests, utilizes 4" square tube chocks to hold the bottom Impact Limiter. These chocks are 6" long and have walls of 3/8" and are intended to prevent horizontal movement. Because of their load bearing capability, these four chocks serve as chain conduits which can be used to anchor the bottom of the package to a conveyance. The combined capabilities of the top and bottom chain points provide a tie-down capability safety factor in excess of 5.

Because these restrictive devices (Spider Frame and Lifting Pallet) are not a functional part of the package they do not influence package performance during HAC and NCT events. The top and bottom Impact Limiters absorb the strain applied by chain anchoring. Minimum chain size should be 5/16" diameter.

2.6 Normal Conditions of Transport

The BU650B as designed and constructed meets the standards specified in 10 CFR 71.43 and 71.51; and meets the requirements of the tests and conditions specified in 10 CFR 71.71. The following paragraphs will show that the BU650B satisfies the performance requirements specified and maintains integrity regardless of the condition to which exposed. Further, based on past operational experience and professional engineering judgment, many of these tests are deemed not to be required.

For purposes of these evaluations, an analysis has been performed using information obtained as a consequence of computerized HAC models and manual calculations. For computer modeling purposes, a detailed model was constructed using LS Dyna and is described in detail at Section 2.12.4 of this document.

- As designed, the BU650B has no feature that is less than 4cm overall.

- As designed, the BU650B has no sealing feature

- The materials of construction used in the fabrication of the BU650B are principally austenitic stainless steels, carbon steels, and an inert thermal barrier product, a foam contained in a sacrificial impact limiter, carbon steel and lead fully encased within the carbon steel. There are no chemical or galvanic reactions resulting from the materials themselves or interaction with other materials. All sources are sealed sources in special form.

    - The BU650B has no valves or other devices that will permit the escape of radioactive materials into the environment.

2.6.1 Heat

As identified in the HAC model at Attachment B there are no issues relevant to Normal Conditions of Transport as they pertain to the BU650B. Paragraphs 2.6.1.1 Summary of Pressures and Temperatures, Paragraph 2.6.1.2, Differential Thermal Expansions; Paragraph 2.6.1.3 Stress Calculations; and Paragraph 2.6.1.4, Comparison with Allowable Stresses are all addressed in Section 3 of this document and documented in Section 3.5.2: Calculation, DAC-P09YCW01-0002-000-00, Thermal Analyses (ANSYS) of JLS&A BU650B Shipping Container for NCT and HAC, Babcock & Wilcox Y-12, Oakridge, TN, April 23, 20123.3. The results of the DAC Calculation show that there are no heat issues associated with Normal Conditions of Transport as they relate to this package. Insolation is addressed in Table 2-17, below.

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Table 2-17

BU650B (450 Watts); Steady-State Temperatures (100°F ambient, no insolation)

Temperature locations	Maximum steady-state temperature (°F)
Outside Shell Lid Top	113.4
Outside Shell Bottom	156.9
Kaolite Middle	147.3
Outside Shell Mid-Height	121.8
Inner Shell Mid-Height	176.9
Shielded Liner Cavity	286.6
Shielded Liner Surface	275.9

Table 2-18

BU650B (450 watts); Maximum "Quasi Steady-State" Temperatures during NCT

Temperature locations	Maximum quasi steady-state temperature (°F)
Outside Shell Lid Top	245.3
Outside Shell Bottom	229.7
Kaolite Middle	229.4
Outside Shell Mid-Height	210.5
Inner Shell Mid-Height	253.6
Shielded Liner Cavity	334.8
Shielded Liner Surface	323.9

2.6.2 Cold

Based upon the material selection contained in the design (austenitic stainless steels) there are no issues with extreme cold as they relate to brittle fracture. Additionally, where a carbon steel is used, it is used in the Shielded Liner which is not affected by extreme cold based upon the decay heat generated by the radioactive contents.

2.6.3 Reduced External Pressure

The BU650B package, as designed, as no sealing surfaces. Therefore this item is not addressed.

2.6.4 Increased External Pressure

The BU650B package maintains atmospheric equilibrium at all times due to not having a sealing surface. Sealed Sources are typically constructed of stainless steel tubing have a minimum wall thickness of .020" and are doubly encapsulated right cylinders. Exposed to an increase in atmosphere as a consequence of deep water immersion (290 psi), the sealed source would maintain a safety factor of 2.1. Therefore there are no significant safety issues, to include risk of buckling, associated with an increased external pressure applied to the BU650B.

2.6.5 Vibration

As discussed in Section 2 of this document and demonstrated by calculations therein, the BU650B package has no issues with vibration that would result in a failure or fatigue of any component over the estimated 20 year package life-cycle.

2.6.6 Water Spray

Although the BU650B package has no sealing surfaces, it does maintain use of sealed sources. Because sealed sources are welded containments and are leak tested at manufacture and verified to be "leak free" periodically, in leakage of water into the package core is considered insignificant.

2.6.7 Free Drop

The BU650B, as demonstrated by computer- simulated HAC tests and models (See Section 2.12.3 of this document), will not be affected by a drop from 1 meter to an unyielding surface, regardless of orientation.

2.6.8 Corner Drop

The BU650B, as demonstrated by HAC tests and models (See Section 2.12.5 to this document) will not be affected by a drop to either corner from 1 meter to an unyielding surface.

2.6.9 Compression

The BU650B package has a maximum gross weight of 12,500 pounds and is therefore exempt from the compression test.

2.6.10 Penetration

The BU650B, as demonstrated by HAC test, was not impaired by drop from 1 meter onto a 6" diameter peg at its weakest point (side drop). The results of that test clearly indicate the package would survive the penetration test prescribed in §71.71.

2.7 Hypothetical Accident Conditions

The package meets the standards specified in §71.51 when subjected to the HAC tests specified in §71.73. In accordance with Regulatory Guide 7.6, "design-by-analysis" is used for the structural evaluation of the package. The structural evaluation for HAC is based on sequential application of the HAC tests specified in §71.73 to determine the cumulative effect on the package, in accordance with §71.73(a). As discussed in Section 2.6, no significant package damage results from the NCT tests of §71.71. Thus, the evaluation of the package for the HAC test sequence is performed starting with an undamaged specimen. The package is evaluated for the most unfavorable initial conditions specified in §71.73(b). The HAC load combinations considered in the structural evaluation are developed in accordance with Regulatory Guide 7.8 and summarized in Section 2.1.2.1.

The results of the structural evaluation show that the BU650B satisfies the applicable allowable stress design criteria of the ASME BPVC when subjected to the HAC tests of §71.73. A summary of the cumulative

BU650B package damage resulting from the HAC tests is provided in Tables 2-10A and 2-10B. The predicted damage is considered in the BU650B package thermal, containment, and shielding HAC evaluations. The containment and shielding evaluations of the BU650B show that the cumulative package damage resulting from the HAC test sequence results in no escape of radioactive material exceeding a total amount of A_2 in one week and no external radiation dose rate exceeding 10 mSv/h at 1 m from the external surface of the BU650B package, in accordance with §71.51(a)(2).

2.7.1 Free Drop Test

In accordance with §71.73(c)(1), the package is subjected to a free drop through a distance of 9 m "*onto a flat, essentially unyielding, horizontal surface, striking in a position for which maximum damage is expected.*" The package is evaluated for a total of 19 different HAC free drop conditions, including eighteen different HAC free drop orientations. These HAC free drop conditions are summarized in Table 2-10A and 2-10 B. They include upper-bound and lower-bound analyses for a bottom end drop, a top end drop, a bottom corner drop, a top corner drop, a horizontal side drop, fifteen different oblique drop angles. The dynamic response of the package to the HAC free drop test conditions is determined using explicit dynamic finite element analysis methods. The ANSYS LS-DYNA PC computer code which is described in Section 2.12.4 and 2.12.5 is used for this analysis.

In accordance with the requirements of Regulatory Guide 7.8, the worst-case initial conditions are considered. For each HAC free drop impact orientation considered, upper-bound and lower-bound analyses are performed. The upper-bound analyses are performed using the package material upper-bound strength properties for the "cold" thermal condition temperature of -29°C with a lower-bound package mass of 5,682 kg. The upper-bound analyses produces the maximum peak rigid-body package accelerations that are used for the package stress analysis. The lower-bound analyses are performed using the package material lower-bound strength properties for the "hot" thermal condition ambient temperature of 38°C, maximum decay heat, and insolation, combined with an upper-bound package mass of 5,682 kg. The lower-bound analyses, which produce the maximum package deformation and the lowest peak rigid-body package acceleration, are evaluated to assure that the package will not "bottom-out," causing large impact loads to be imparted to the Shielded Liner. The explicit dynamic finite element analysis of the package is used to predict the rigid-body response of the package to each HAC free drop test. In addition, this analysis demonstrates the structural adequacy of the package assembly for the HAC free drop tests. The maximum stresses in the package closure bolts are shown to satisfy the applicable allowable stress design criteria described in Section 2.1.2.2. Furthermore, the maximum crush depth of the package Kaolite 1600 due to each HAC free drop is shown to be less than the allowable crush depth of 4". The drop loads analysis of the package for each HAC free drop impact orientation are discussed in the following sections.

Detailed stress analyses of the package and shield lid for HAC free drop loading are performed using linear-elastic equivalent-static finite element analysis methods. The ANSYS Mechanical computer program, which is described in Section 2.12.4, is used for this analysis. Bounding equivalent-static acceleration design loads are applied to the package finite element model for each HAC free drop orientation. The bounding equivalent-static acceleration design loads are determined by multiplying the package peak rigid-body accelerations for each HAC free drop condition by a DLF to account for possible dynamic amplification within the Shielded Liner.

In accordance with Regulatory Guide 7.8, HAC free drop loads are evaluated in combination with internal pressure (not considered in this application), thermal, and fabrication stresses. A bounding internal design pressure is not used for the structural evaluation of the package, due to the elimination of sealing surfaces. NCT cold and NCT hot thermal loading are considered in combination with HAC free drop loading. Thermally induced stress intensities are classified as secondary in accordance with the ASME BPVC, since they are self-limiting, and do not require evaluation for HAC. Furthermore, the only significant stresses in the package body due to NCT thermal loading result from differential thermal expansion of the closure bolts and closure lid. The stresses elsewhere in the package are not significantly affected by NCT thermal loading, as shown by the results of the NCT end drop evaluation discussed in Section 2.6.7. Therefore, NCT thermal loading is not included in the HAC free drop load combinations. However, the effects of elevated temperature are considered for differential thermal expansion between the closure bolts and closure lid and for material properties and allowable stresses used for the HAC free drop evaluation. Furthermore, the only significant fabrication and assembly stresses in the package are those resulting from closure bolt preload. Therefore, the following load combinations are considered for each HAC free drop load orientation evaluated:

HAC Free Drop + Bolt Preload

The maximum stresses in the package and shield lid due to each HAC free drop are calculated and shown to satisfy the applicable allowable stress design criteria of Subsection NF and Subsection WB of the ASME BPVC. In addition, the compressive stresses in the package cylindrical shells due to each HAC free drop are evaluated in accordance with ASME BPVC Case N-284-1 and shown to satisfy the applicable buckling design criteria. The package stress analysis and buckling analysis for each HAC impact orientation are discussed further in the following sections. The results of the HAC free drop structural evaluation demonstrate that the package satisfies the applicable HAC allowable stress design criteria. HAC free drop loading does not cause any significant permanent deformation of the package, nor does it substantially reduce the effectiveness of the packaging. The evaluation shows that, under HAC free drop, the containment (sealed source) is maintained, and there is no loss or dispersal of radioactive contents. The damage to the package resulting from HAC free drop loading is considered in the HAC shielding evaluation, which demonstrates that the external dose rate limit requirement of §71.51(a)(1) is satisfied. Therefore, the package complies with the requirements of §71.51(a)(1) when subjected to the HAC free drop test of §71.73(c)(2).

2.7.1.1 End Drop

The BU650B package was subjected to a series of end drops, both top and bottom. As a consequence of the drop applied at 15 degrees, the most damaging orientation was discovered. Table 2-16 identifies the maximum impact damage (true plastic strains) in the BU650B packaging components after the cumulative damage from the worse-case 30 ft Top Drop (rotated 15 degrees). The results establish that the package meets the criteria of 10 CFR 71.73 (c)(1).

2.7.1.2 Side Drop

The package was subjected to side drops ranging from 60 to 90 degrees. No particular drop orientation produced damage sufficient to result in plastic deformation sufficient to induce a component or sub-assembly failure. The results indicate the package meets the criteria of 10 CFR 71.73 (c)(2).

2.7.1.3 Corner Drop

The package was subject to a series of corner drops between 30 and 60 degrees. No particular drop orientation produced damage sufficient to result in any plastic deformation sufficient to induce a component or sub-assembly failure. The results indicate the package meets the criteria of 10 CFR 71.73 (c)(3).

2.7.1.4 Oblique Drops

A number of oblique drops were performed at angles ranging between 0 and 90 degrees. No drop, other than the 15 degree top drop, produced sufficient measurable damage to impart a risk of any component or subassembly system failure. The results indicate the package meets the criteria of 10 CFR 71.73 (c)(4).

2.7.1.5 Summary of Results

Table 2-16 identifies the true plastic strains (not engineering strains) of all components (excluding the foam and Kaolite components) after the cumulative damage from a 30 ft Top Drop (rotated 15 degrees) and the 40 inch drop puncture both on the outer lid (center) and outer cylinder side. The final cumulative damage data shows the outer lid (Item 29) and outer cylinder (Item 4) will not be penetrated / ruptured into the Kaolite region from the puncture test. This was expected since the impact limiters absorb the vast majority of the drop test energy and the Kaolite at these puncture impact regions are not compacted prior to the puncture impacts.

2.7.2 Crush

The BU650B has a maximum gross weight of 12,500 pounds and an approximate empty weight of 5,800 pounds. Accordingly, the provisions of 10 CFR 71.73 (c)(2) do not apply.

2.7.3 Puncture

The puncture test was applied to the most vulnerable surfaces of the package: at the Lid Assembly center and Lower Package Assembly center. The most damaging results were realized as a consequence of the side-center punch. The final cumulative damage data (See Table 2-19) shows the outer lid (Item 29) and outer cylinder (Item 4) will not be penetrated / ruptured into the Kaolite region from the puncture test. The BU650B outer closure bolts are the single most important items which maintain confinement of the inner shield liner contents inside of the BU650B packaging after all cumulative HAC impact tests. Table 2-11 identifies the maximum true plastic strain value of from the outer closure bolts outer bolt materials (Items 10) and and inner core bolt volumes (Items 119) of 17.73% and 15.82%, respectively. Based on any comparison to the (true) strain at failure of the materials of these components, it is certain these bolts will not fail during HAC impact testing as modeled and contains adequate margin of safety. Also note these maximum plastic strains obtained and identified is the maximum in all bolts and not the average in each bolt or bolt material section.

Figure 2-3 depicts the expected damage from a side punch. Figure 2-4 illustrates the deflection and resulting impression of the punch into the side of the package. Note the package side wall does not yield.

The package as configured does not have valves or fittings affixed. Therefore consideration is given only to survivability of the closure and containment mechanisms. Since containment is achieved through the limitation of Sealed Sources in Special Form (§71.75) and there is no breach of tertiary containment into the package interior, the secondary and primary containments remain undamaged by both the drop and puncture tests. Therefore the package meets the requirements of 10 CFR 71.73 (c)(3).

Table 2-19

BU650B Component Maximum Plastic Strains; Cumulative Damage from 30 ft Top Drop (rotated 15 deg) and 40 inch Puncture Drop (Lid and Side)

Part #	Part Identification	15 deg from Top	
		Lid Punch (% Strain)	Side Punch (% Strain)
1	Package Body Outer Btm Plate	3.75	5.72
2	Package Body Inside Btm Plate	0.86	0.88
3	Package Body Btm Plate Lip	0.53	0.54
4	Package Body Outer Cylinder	0.72	3.93
5	Package Body Inside Cylinder	1.60	1.60
6	Package Body Top Closure Ring	21.61	23.22
8	Package Body Welded Nut	4.46	3.55
10	**Package Outer Bolt**	**16.71**	**17.73**
12	Package Body Washers	1.11	1.18
25	Package Lid Bolting Plate	5.08	5.10
26	Package Lid Mid Plate	10.22	1.88
27	Package Lid Out Cyl	13.02	13.12
28	Package Lid Ins Cyl	5.72	4.71
29	Package Lid Top Plate	15.38	11.98
30	Package Lid Out Cyl w/Weld	68.56	68.83
31	Package Lid Ins Plate	18.00	17.27
32	Package Lid Ins Cyl w/Weld	20.83	19.47
33	Inside Shoring	40.65	40.12
45	Impact Limiter Shell; Upp Horiz Plt	15.46	15.60
47	Impact Limiter Shell; Ins Horiz Plt	30.36	30.46
49	Impact Limiter Shell; Mid Ins Vert Cyl	33.21	26.82
51	Impact Limiter Shell; Ins Vert Cyl	86.25	77.41
53	Impact Limiter Shell; Out Vert Cyl	9.20	9.09
55	Impact Limiter Shell; Btm Out Horiz Plt	6.20	6.16
57	Impact Limiter Inner Angle	37.51	36.59
70	Lifting Ring; Impact Limiter	19.07	28.67
72	Bolting Lug; Impact Limiter	69.01	66.41
73	Pins; Package Body / Impact Limiter	38.57	38.07
76	Shield Liner Shell	109.08	87.22
91	Shield Liner Lead	3.73	3.70
100	Shield Liner Lid Closure Shell	39.19	39.41
104	Shield Liner Lid Lead	1.29	1.35
105	Shield Liner Content	0.00	0.00
106	**Shield Liner Bolts**	**2.68**	**2.94**
109	Shield Liner Washers	1.10	1.27
112	4x4 Mounting Bracket; Package Body	4.95	4.96
113	Mounting Bracket Lug; Package Body	57.24	55.39
114	Mounting Brackets Welds	8.04	8.24
119	**Package Body Bolts Core**	**15.73**	**15.82**
121	**Shield Liner Bolts Core**	**1.31**	**1.45**
124	Impact Plate on Shield Liner	40.92	44.56

Figure 2-3

BU650B Inner and Outer Cylinder Cumulative Plastic Strain (3.94%) (Parts #4 & 5) (30 ft Top Impact rotated 15 degrees plus 40 in Side Puncture)

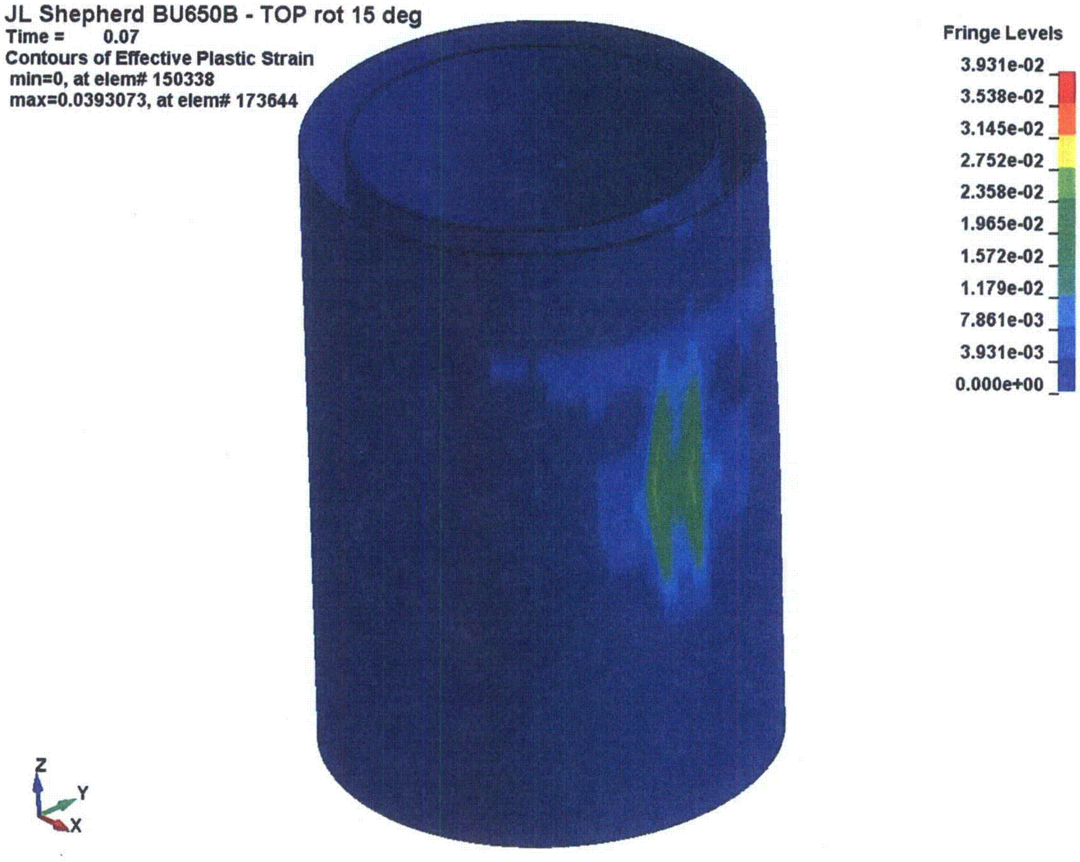
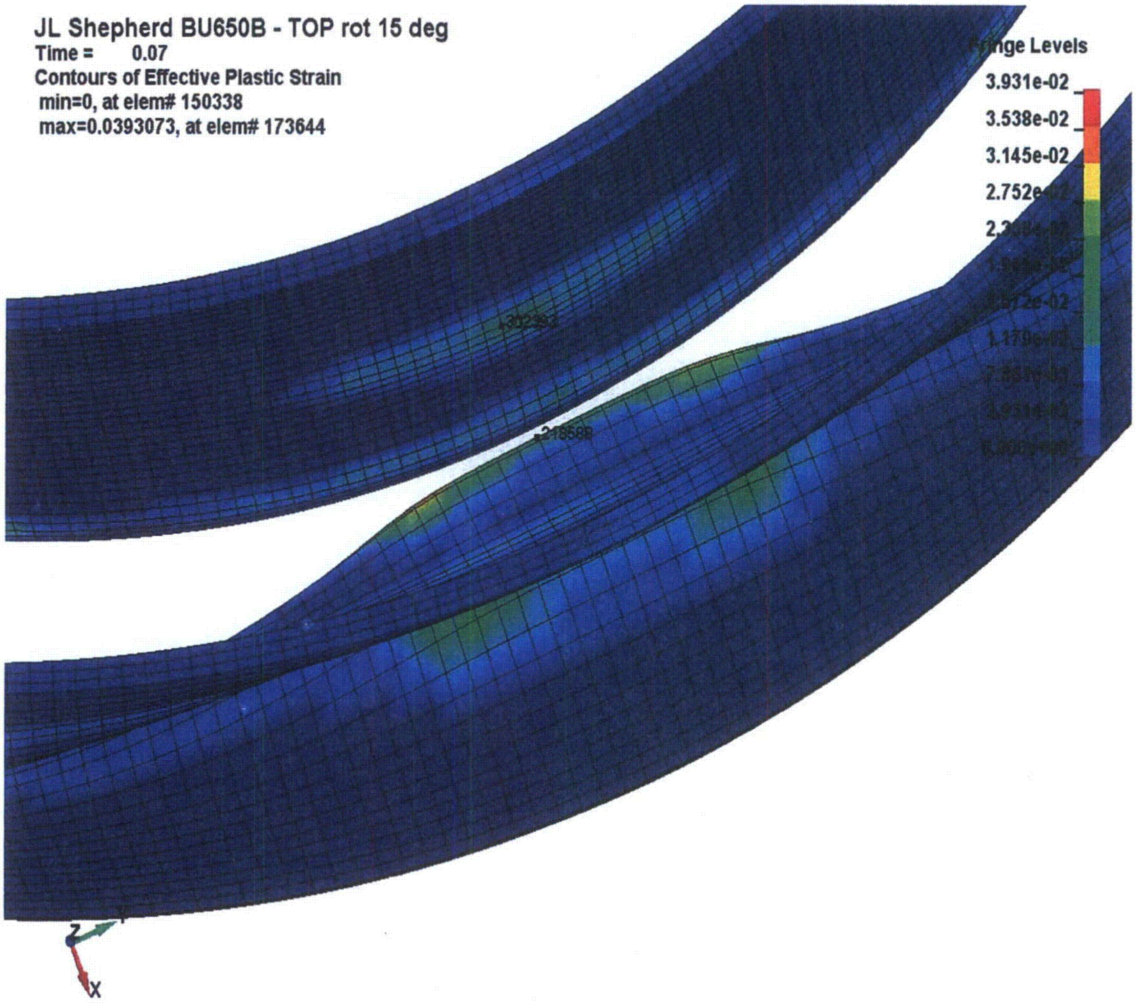


Figure 2-4

BU650B Inner and Outer Cylinder Minimum Distance is ~ 1.65 inch between Nodes 218588 and 302393 (Parts #4 & 5) (30 ft Top Impact rotated 15 degrees plus 40 in Side Puncture)



The results of the Puncture Test indicate that the package closure and side wall will not yield, retaining the Kaolite 1600 thermal barrier. Containment of the sealed source is not threatened by the drop, puncture, or thermal tests identified in §71.73, and as a result, the package remains compliant with 10 CFR 71.73 (c)(1 through 3).

2.7.4 Thermal

The BU650B was subjected thermal evaluation (See Design Calculation DAC-P09YCW01-002-000-00) in accordance with the instructions and sequencing required in 10 CFR 71.73. Results of the thermal evaluation are explained in the paragraphs and tables below.

During the 30' Drop and Puncture Tests identified in §71.73 (c)(1 through 3) assessments of damage from the sequence of tests was identified and recorded. Those sections of the grid model were again reviewed upon completion of the thermal evaluation. The results achieved clearly indicate that the Sealed Source, as carried by the design, remains intact and does not become a risk of exposure or danger to public safety as a consequence of HAC thermal event. Because the package is designed from inert components, there is no decomposition of materials or secondary combustion occurring as a result of extreme heat. Given the package payload at 450 watts, the maximum temperature realized at the package interior center is 347.5°F, at the center of the Shielded Liner (closest to sealed source), the temperature realized was 371.1°F. This extreme produces a safety factor of 1.7, based solely on the melting point of lead and not based upon the thickness of the lead shielded used (10") and the time necessary to heat the volume of lead to its melting point. The thermal stresses occurring as a result of or during the application of heat are insignificant and do not reach a level sufficient to have an effect upon the package component integrity.

2.7.4.1 Summary of Pressures and Temperatures

Temperatures resulting from HAC are shown in Tables 2-17 below.. There are no pressures associated with these temperatures as a consequence of HAC thermal event.

Table 2-20

BU650B HAC Maximum Temperatures

HAC maximum temperature (°F)				
Temperature Locations	No Heat Load		450 W Heat Load	
	Insolation during cool-down?		Insolation during cool-down?	
	No	Yes	No	Yes
Outside Shell Lid Top	1407.1	1407.1	1407.6	1407.6
Outside Shell Bottom	1439.8	1439.8	1444.0	1444.0
Kaolite Middle	551.3	553.2	601.4	603.4
Outside Shell Mid-Height	1452.5	1452.5	1453.4	1453.4
Inner Shell Mid-Height	263.5	272.4	337.6	345.7
Shielded Liner Cavity	150.1	165.8	348.4	371.1
Shielded Liner Surface	150.2	165.9	359.4	360.0

2.7.4.2 Differential Thermal Expansion

The calculated temperature differences between the baseline case and various HAC cases are presented in Table 2-18. There are no instances of circumferential and axial deformations and stress occurring as a result from differential thermal expansion at peak, post-fire steady state or transient conditions.

Table 2-21

BU650B HAC Temperature Differences from Baseline

ΔT (°F)				
Temperature Locations	No Heat Load		450 W Heat Load	
	Insolation during cool-down?		Insolation during cool-down?	
	No	Yes	No	Yes
Outside Shell Lid Top	---	0.0	0.5	0.5
Outside Shell Bottom	---	0.0	4.2	4.2
Kaolite Middle	---	1.9	50.1	52.1
Outside Shell Mid-Height	---	0.0	0.9	0.9
Inner Shell Mid-Height	---	8.9	74.1	82.2
Shielded Liner Cavity	---	15.7	198.3	221.0
Shielded Liner Surface	---	15.7	209.2	209.8

2.7.4.3 Stress Calculations

Because of the low temperatures achieved as a consequence of HAC there are no stresses resulting from differential expansion, pressure or other mechanical load. Due to compatibility of materials there are no significant stresses occurring as a consequence of thermal gradient.

2.7.4.4 Comparison with Allowable Stresses

The BU650B, as designed, meets the standards identified in §71.73(c)(4). The package, when subjected to thermal evaluation, does not sustain sufficient thermally generated stresses that would result in the failure of any component or sub-assembly. As a consequence of the low stresses realized, the requirements of 10 CFR 71.73 (c)(4) are met.

2.7.5 Immersion – Fissile Material

The BU650B is not intended for the transport of fissile materials. Therefore this section is not applicable.

2.7.6 Immersion – All Packages

The BU650B, if submerged under a 15m column of water would experience a pressure load of 21.7 psi. The BU650B has no sealing surfaces, therefore an in-leakage of water would result due solely to the pressure differential. Once equilibrium was achieved, the pressure of 27.1 psi would then be applied to the sealed source surface. That surface is typically manufactured from .020 wall grade 304 stainless steel having a yield strength of 1,750 psi. The resulting calculation reflects a safety factor of 32. Beyond the outer capsule wall is an inner wall of .020 thick grade 304 stainless steel. That wall produces a safety factor against failure of 32. Therefore, submersion under a 15m column of water has no negative effect on the Sealed Source containment or other mechanical features of the BU650B package. The BU650B package meets the requirements of 10 CFR 71.73 (c)(6).

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 105 A2).

The package, if submerged under deep water would experience a pressure load of 290 psi. The BU650B has no sealing surfaces, therefore an in-leakage of water would result due solely to the pressure differential. Once equilibrium was achieved, the pressure of 290 psi would then be applied to the sealed source surface. That surface is typically manufactured from .049 wall Grade 304 stainless steel having a yield strength of 1,750 psi. The resulting calculation reflects a safety factor of 6. Beyond the outer capsule wall is an inner wall of .020 thick grade 304 stainless steel. That wall produces a safety factor against failure of 2.4. Therefore, a deep water submersion producing an external pressure of 290 psi has no negative effect on the Sealed Source containment or other mechanical features of the BU650B package. The BU650B package meets the requirements of 10 CFR 71.61.

2.7.8 Summary of Damage

After completion of all test events, the BU650B package sustained minimal physical damage as a consequence of the 30' Drop Test and Puncture Test. These tests, when combined with the results of the thermal evaluation indicate the BU650B package is robust and provides excellent safety characteristics. No test applied provided damage sufficient to result in breach of any main BU650B package surface or feature intended to protect the radioactive contents. Upon examination of all test results, should the BU650B package be exposed to an accident resulting in a sequence of events similar to those outlined in the HAC, the BU650B package would remain intact. Therefore the BU650B package meets the requirements of both 10 CFR 71.71 and 10 CFF 71.73.

2.8 Accident Conditions for Air Transport of Plutonium

This BU650B package is not intended for transport of Plutonium. Therefore this condition is not applicable or addressed.

2.9 Accident Conditions for Fissile Material Packages for Air Transport

This BU650B package is not intended for transport of fissile materials. Therefore this condition is not applicable or addressed.

2.10 Special Form

This package is designed to transport radioactive material only in special form and the contents meet the requirements identified in 10 CFR 71.75 when subjected to the applicable test conditions of 10 CFR 71.77. The chemical and physical forms of the principal isotopes intended to be carried in this package are solids. The chemical form of Co-60 is Cobalt metal; in rods, discs or pellet form. The chemical form of Cs-137 is Cesium Chloride, a powder that is typically compressed into pellets prior to encapsulation into Sealed Sources. Sealed sources are typically doubly encapsulated right cylinders of welded construction, having various diameters and lengths capable of transport within Shielded Liners, but at no combined mass greater than 25 pounds.

- All Special Form Sources are required to:

  1. Be physically compatible with the Shielded Liner.
  2. Have a current Leak Test.
  3. Be certified to meet the requirements of 10 CFR 71.75

2.11 Fuel Rods

This package is not intended for the transport of spent fuel, fuel rods or nuclear fuels in any form, therefore this section is not applicable or addressed.

This section intentionally left blank

2.12 Appendix

2.12.1 References

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[2.2] Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material*, Revision 2, March 2005.

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[2.15] American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section II, *Materials*, Part B, *Nonferrous Material Specifications*, 2001 Edition with Addenda through July 1, 2003.

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[2.17] Penton Publications, *Materials Engineering, Materials Selector 1990*, December 1989.

[2.18] American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section IX, *Welding and Brazing Qualifications.* Latest Edition.

[2.19] ANSI N14.23, *Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater Than One Ton in Truck Transport*, American National Standards Institute, Inc., New York, 1980.

[2.20] Blevins, R. D., *Formulas for Natural Frequency and Mode Shape*, Van Nostrand Reinhold Company, 1979.

[2.21] NUREG/CR-3966, *Methods for Impact Analysis of Shipping Containers*, UCID-20639, U. S. Nuclear Regulatory Commission, November 1987.

[2.22] J.L. Shepherd & Associates Engineering Specification, JLS ES-002, Rev 3, *Specification for Installation, Inspection, and Testing of Rigid, Closed-cell Polyurethane Foam Utilized Within BU650B Cask Assembly Impact Limiters,* June 7, 2012

2.12.2 Table of Weights (From DAC-P09YCW-01-0001)

BU650B LS-DYNA Model Mass / Weights

Part	Description	Material	Mass in Model	Total Weight (lb)
1	Package Body Outside Btm Plate	Grade 304 SS	0.564667000	217.96
2	Package Body Inside Btm Plate	Grade 304 SS	0.361407000	139.50
3	Package Body Inside Btm Plt Ext Lip	Grade 304 SS	0.037044200	14.30
4	Package Body Outer Cyl Wall	Grade 304 SS	2.489770000	961.05
5	Package Body Inner Cyl Wall	Grade 304 SS	1.816070000	701.00
6	Package Body Top Closure Ring	Grade 304 SS	0.217937000	84.12
8	Package Bolts - Welded Nuts	316L SS	0.040923900	15.80
10	Package Bolts – Outer	316L SS	0.018457600	7.12
12	Package Washers	316L SS	0.002560640	0.99
13	Package Body Kaolite	Kaolite 1600	1.216810000	469.69
25	Package Lid Top Bolting Flange	Grade 304 SS	0.258422000	99.75
26	Package Lid Middle Plate	Grade 304 SS	0.321283000	124.02
27	Package Lid Outside Cyl Wall	Grade 304 SS	0.029613000	11.43
28	Package Lid Inside Cyl Wall	Grade 304 SS	0.081426000	31.43
29	Package Lid Top Plate	Grade 304 SS	0.193902000	74.85
30	Package Lid Outside Cyl Wall w/Weld	Grade 304 SS	0.003357470	1.30
31	Package Lid Btm Inside Plate	Grade 304 SS	0.346082000	133.59
32	Package Lid Inside Cyl with Weld	Grade 304 SS	0.006346150	2.45
33	Inside Shoring	Grade 304 SS	0.498215000	192.31
45	Impact Limiter Shell Upper Horiz Flat	Grade 304 SS	0.333257000	128.64
47	Impact Limiter Shell Inside Horiz Flat	Grade 304 SS	0.171201000	66.08
49	Impact Limiter Shell Inside Mid Cyl	Grade 304 SS	0.311455000	120.22
51	Impact Limiter Shell Inner	Grade 304 SS	0.124960000	48.23
53	Impact Limiter Shell Outer Cyl	Grade 304 SS	0.812105000	313.47
55	Impact Limiter Shell Outer Flat	Grade 304 SS	0.504454000	194.72
57	Impact Limiter Shell Inner Angle	Grade 304 SS	0.353428000	136.42
63	Impact Limiter Foam	GP FR-3712	2.178560000	840.92
70	Impact Limiter Lifting Ring	Grade 304 SS	0.148972000	57.50
72	Impact Limiter Bolting Lugs	Grade 304 SS	0.012352300	4.77
73	Impact Limiter Attachment Pins	Grade 304 SS	0.005871020	2.27
76	Shield Liner #1 Shell	AISI 1010 CS	0.886870000	342.33
91	Shield Liner #1 Body Lead	Lead	15.467200000	5970.34
100	Shield Liner #1 Lid Shell	AISI 1010 CS	0.085146100	32.87
104	Shield Liner #1 Lid Lead	Lead	0.894018000	345.09
105	Content in Shield Liner #1	Grade 304 SS	0.064500600	24.90
106	Shield Liner #1 Bolts	AISI 1020 CS	0.003972320	1.53
109	Shield Liner #1 Washers	AISI 1020 CS	0.000613711	0.24
111	Package Body Lid Kaolite	Kaolite 1600	0.123484000	47.66
112	Package Body Mounting Brackets	Grade 304 SS	0.043602100	16.83
113	Package Body Mounting Lugs	Grade 304 SS	0.008828060	3.41
114	Package Body Mounting Plate Welds	Grade 304 SS	0.003750190	1.45
118	Unyielding Impact Surface	Rigid Mat	0.004999980	1.93
119	Package Bolts - Core Volume	316L SS	0.004056920	1.57
121	Shield Liner Bolts Core Volume	AISI 1020 CS	0.000514232	0.20
124	Shield Liner Impact Plt - Protect Bolts	Grade 304 SS	0.054417200	21.01
Empty Package Body Weight including Impact Limiters				**5074.52**
Shield Liner #1 Empty Weight w/Impact Plate				**6713.60**
Shoring Weight				**192.31**
Content Weight				**24.90**
Total Package, Shield Liner #1, Content, Shoring				**12005.33**

2.12.3 Computer Code Descriptions

The structural evaluation of the package includes analyses performed using the ANSYS/Mechanical and ANSYS LS-DYNA PC modules of the ANSYS Release 10.0 computer program. These programs are both run on a PC platform under the Windows XP operating system. Descriptions of the models used to perform the structural analyses are provided in the respective sections of this chapter. Descriptions of these computer codes are provided in this section and the sections that follow. The ANSYS computer code is acquired from and supported by ANSYS Incorporated as a fully-compiled executable program. The ANSYS/Mechanical and ANSYS LS-DYNA PC modules of the ANSYS computer code are tested, installed, operated, and maintained in accordance with the requirements of the JLS&A QA program. Prior to use for quality-affecting work, several validation test problems are solved using the ANSYS ANSYS/Mechanical and LS-DYNA PC computer codes. The validation tests include a large number of test problems included in the ANSYS Verification Manual and other independent test problems with solutions that are known either by classical means or by comparison to computer solutions that have been reviews and accepted by JLS&A. The validation tests demonstrate that the computer codes correctly solve the general classes of problems for which they will be used. Errors in the ANSYS computer codes are identified and controlled in accordance with the requirements of the JLS&A QA program. All errors that are discovered either internally or externally are reviewed for impact on past and present work, and potential impact on future work. Errors that are identified to have potential impact on work are evaluated using the Corrective Action Process of the JLS&A QA program.

2.12.3.1 ANSYS Mechanical

The ANSYS/Mechanical computer code is an implicit finite element program that is used to solve a wide range of structural, heat transfer, and electromagnetic problems. The use of the ANSYS/Mechanical computer code for the structural analysis of the package is limited to mode-frequency analysis, and static structural analysis using linear-elastic material properties and non-linear contact behavior.

2.12.3.2 ANSYS LS-DYNA PC

The ANSYS LS-DYNA PC computer code combines the LS-DYNA explicit finite element program with the pre- and post-processing modules of the ANSYS program. The ANSYS LS-DYNA PC computer code is well-suited to simulate short-duration, large deformation dynamic impacts and complex contact problems. The code has been well benchmarked and is widely used for the structural analysis of transportation package drop tests.

2.12.4 Dynamic Load Factors

The stresses in the BU650B package due to NCT and HAC free drop loading are calculated using equivalent-static linear-elastic finite element analyses. The equivalent static acceleration loads for each NCT and HAC free drop test are equal to the peak rigid-body accelerations of the package, multiplied by a Dynamic Load Factor (DLF) that accounts for possible dynamic amplification within the BU650B package. The DLF is a function of the general shape of the rigid-body acceleration time history pulse and ratio of the duration of the rigid-body acceleration time-history to the package period (t/T).

Longitudinal vibration modes of the package that are of interest for the NCT and HAC free drop analysis include the axial compression/extension mode of the cask's Outer Shell and the plate bending mode of the Lid Assembly.

The natural frequency of the BU650B Outer Shell in compression, as determined by hand calculation, is 1,121 Hz, based upon a bounding temperature of 93°C. This is calculated using Case 1, Table 6-2 of Blevins [2.22]

The natural frequency of the BU650B Closure Lid in bending is determined using hand calculation, as 1,066 Hz, based upon a bounding temperature of 93°C.

2.12.5 Confirmatory Tests

2.12.5.1 Confirmatory Test Report

This section includes the confirmatory test report that provides a summary of the confirmatory testing performed to demonstrate the adequacy of the analytical methodologies used to predict the structural and thermal response of the package for the NCT free drop, HAC free drop, HAC puncture, and HAC thermal tests. The results of the confirmatory tests are summarized and compared to pre-test predictions determined using the same analytical methodology as the safety analyses. In general, the results of the confirmatory tests show good agreement with the pre-test predictions. In those instances where the test conditions deviated from the test plan or significant differences existed between the test results and the pre-test predictions, a reconciliation analysis was performed. The confirmatory drop test reconciliation analysis is included in Section 2.12.4.2. (Attachment: Report No. DAC-P09YCW01-0001-000-00, "LS DYNA Impact Analysis of the J.L. Shepherd & Associates Model BU650B Radioactive Materials Package").

2.12.6 Hand Calculation Supporting Section 2.1.1.1, Shielded Liner Assembly, Sub-Paragraph 4:

Mass of Shielded Liner: 6,500 pounds

Catalog rating of 1" Lifting Eye: 9,000 lbs (forged steel) 1"-8 UNC.

Two lifting eyes per Shielded Liner

Capability = Rating / Mass

Capability = 1.38 per Lifting Eye

Combined: 2.76

J.L. Shepherd & Associates
1010 Arroyo Ave.
San Fernando, CA 91340

QUALITY RECORD

DESIGN CALCULATION SHEET

Job/Blueprint Number: 98-5159

Calculation No.: DAC-P09YCW01-0001 000 00

Total Number of Pages: 88

Revision No.: 0

Title/Scope: LS DYNA IMPACT ANALYSIS OF JLS & A MODEL BU650B RADIOACTIVE MATERIALS PACKAGE

Design Input/Assumptions/References: SEE ATTACHED

Methodology/Formula/Computer Program Used (if any): SEE ATTACHED

CALCULATION: SEE ATTACHED.

(ATTACH ADDITIONAL SHEETS AS NECESSARY AND MARK TOTAL NUMBER OF PAGES ABOVE)

RESULTS/CONCLUSIONS:

SEE ATTACHED PAGE 77

Prepared By: W. BROWN **Verified By:** M. SHEPHERD M. Shepherd per MPB MFS
(Print Name / Initial) **(Print Name / Initial)**

Approved By: QUE PHO **Date:** 06-28-12
(Print Name / Sign Name)

Form 3-2-1
Rev 2, 6-25-08

Design Analysis and Calculation
Title Page

Calculation No:	DAC-P09YCW01-0001 000 00
Calculation Title:	LS-DYNA Impact Analyses of the JL Shepherd & Associates Model BU650B Radioactive Materials Package

Calculation Status:	Preliminary ☐	Contains Unverified Assumptions ☐	Verified ☒	Superseded ☐	Voided/Cancelled ☐

Preparer's Org:	Engineering (Packaging)	**SSC Grade:**	N/A
Project/Task Name:	JL Shepherd & Associates Model BU650B Radioactive Materials Package		

Abstract (e.g., What, Why, How, Results):

Determine the impact response in various components of the JL Shepherd & Associates Model BU650B Shipping Package during hypothetical accident condition (HAC) impacts per applicable 10 CFR 71 requirements. The results will be used to determine the worse-case drop orientations for physical testing.

Assumptions requiring subsequent verification:

None

Software packages used:

LS-DYNA_971, Revision 53450, Version Date 06/08/2009, Precision Single(I4R4), SMP Enabled

TrueGrid Version 2.3.4, 12/31/09, XYZ Scientific Applications, Inc.

The ep0164 computer processor type and operating system version is Dell Precision PWS670, Intel Xeon CPU 3.6 GHz and Microsoft Windows XP Professional Version 2002.

The ep0148 computer processor type and operating system is Dell Precision PWS670, Intel Xeon CPU 3.2 GHz and Microsoft Windows XP Professional Version 2002.

Approvals

Rev. No.	Preparer (Print/Sign)	Date	Verifier/Checker (Print/Sign)	Date	Approver (Print/Sign)	Date
0	D. L. Lowe/ Lance Lowe	4/18/12	D.E. Winder/ Drew	4/18/12	WI North /	4/18/2012

Revisions

Rev. No.	Revision Description
0	Initial Issue

This document has been reviewed by a Y-12 DC/UCNI-RO and has been determined to be UNCLASSIFIED and contains no UCNI. This review does not constitute clearance for Public Release.

Name: Drew Date: 4/18/12

UCN-21944 (06-09)

GENERAL DESIGN AND COMPUTATION SHEET

DAC-P09YCW01-0001 000 00

Job LS-DYNA Impact Analyses of JL Shepherd & Associates Model BU650B Shipping Package	Date 4/19/12	Sheet 1 of 87
ESO No. P09YCW01	Computed by DLL D. L. Lowe	Checked by DEW D. E. Winder

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REVISION LOG

Revision	Date	Description	Total Pages	Affected Pages
0	4/19/12	Initial Issue	Frontmatter, 1 - 4 Body, 6 - 78 Appendix A, 80 - 87	All

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LS-DYNA IMPACT ANALYSES OF JL SHEPHERD & ASSOCIATES MODEL BU650B RADIOACTIVE MATERIALS PACKAGE

D. Lance Lowe

April 19, 2012

INTRODUCTION / PURPOSE

This document summarizes the impact analyses of the JL Shepherd & Associates Model BU650B Shipping Package and resulting maximum plastic strains of the packaging components when exposed to Hypothetical Accident Conditions (HAC) free drop tests as specified in 10 CFR 71.73(c)(1)[Ref 1]. The content within the BU650B for these impact analyses is the Shield Liner (Typical) as identified in dwg BU650B-SL (Rev A)[Ref 2]. The TrueGrid preprocessor software was used to create the finite element model. LS-DYNA was then used as the final computational software with the addition of the system and material properties to the Truegrid output file for each impact analysis run. All runs detailed within this document use the average Kaolite stiffness and density of 22.4 lb / ft^3.

REFERENCES

1. *Packaging and Transportation of Radioactive Materials*, U. S. Nuclear Regulatory Commission, Code of Federal Regulations, Title 10 – Energy, Part 71, January 1, 2007.

2. JL Shepherd & Associates BU650B Shipping Container Drawings

   Drawing BU650B-SL, Rev. A, *Shield Liner (Typical)*
   Drawing BU650B-PA, Rev. 0, *BU650B Package Assembly*
   Drawing BU650B-LPA, Rev. A, *Lower Package Assembly*
   Drawing BU650B-LP-1, Rev. 0, *Lower Package – Top Plate*
   Drawing BU650B-LP-2, Rev. 0, *Lower Package – Inner Can Bottom Plate*
   Drawing BU650B-LP-3, Rev. A, *Lower Package – Outer Can Bottom Plate*
   Drawing BU650B-LP-4, Rev. 0, *Lower Package – Inner Can Form Detail*
   Drawing BU650B-LP-5, Rev. A, *Lower Package – Outer Can Form Detail*
   Drawing BU650B-MB, Rev. 0, *Mounting Bracket*
   Drawing BU650B-IL, Rev. 0, *Top & Bottom Impact Limiter*
   Drawing BU650B-STUD, Rev. 0, *Stud Detail*
   Drawing BU650B-RA, Rev. 0, *Ring Assembly*
   Drawing BU650B-LA, Rev. 0, *Lid Assembly*
   Drawing BU650B-LA-1, Rev. 0, *Lid Assembly – Middle Plate*
   Drawing BU650B-LA-2, Rev. 0, *Lid Assembly – Bottom Plate*
   Drawing BU650B-LA-3, Rev. 0, *Lid Assembly – Top Plate*
   Drawing BU650B-LA-4, Rev. 0, *Lid Assembly – Top Ring Detail*
   Drawing BU650B-LA-5, Rev. 0, *Lid Assembly – Bottom Ring Detail*

3. The software database “Strain” by Dr. Bob Bailey, Version 2.0, LLNL.

4. LS-DYNA Keyword User’s Manual, Version 971, Volume 1, May 2007.

DESIGN INPUTS / ASSUMPTIONS

This document details the plastic strains created from impact simulations which arise from the BU650B shipping container impacting an unyielding surface from a 30 ft drop height per the requirements in 10

CFR 71.73 for hypothetical accident conditions (HAC). The maximum plastic strain values for the cask body bolts and shield liner #1 bolts (core volumes) are used to identify the worst case drop orientation for physical testing. The simulated content inside of the BU650B body is the (typical) shield liner as identified in dwg BU650B-SL Rev A. The simulated content inside of the typical shield liner is a 6-3/4 inch diameter slug of steel with a height of 9 inches with an approximate weight of 25 lbs (by adjustment of material density). Other assumptions including the system and material properties are stated throughout this document.

DESCRIPTION OF THE BU650B SHIPPING CONTAINER AND FINITE ELEMENT MODEL

The BU650B shipping container is an assembly of right cylinders. The most inner cylinder assembly is constructed of stainless steel and provides a "holding area" for a shielded liner. The interior measures 54" high by 35" diameter. The composite side walls are a total of 4.75" thick. The top and bottom composite thickness is 5" thick. All walls are constructed from 304 stainless steel. The cask body lid closure consists of 24 bolts. The inner content is a shield liner which is made of 1/4'" mild steel plate, formed, fully welded and filled with lead. This typical shield liner has a 7" diameter inner cavity with a height of 9-3/8" for holding radioactive sources. Surrounding the inner package is an outer shell constructed of 3/8" 304 stainless steel. All surfaces are heli-arc welded and are full penetration welds. Mounted on the top and bottom of the outer shell assembly is an Impact Limiter assembly. The impact limiters cover the top and bottom and are 10" thick both top and bottom and 12" thick on the sides and are rigidly mounted to the BU650B main body by attachment pins in 4 locations, both top and bottom. Within each impact limiter are eight ribs which provide rigidity to externally mounted attachment lugs. Each impact limiter is filled with General Plastics Last-A-Foam, FR-3712, with an approximate density of 12 lbs / ft^3. Figure 1 illustrates the outside view (unmeshed) of the BU650B packaging.

A typical shielded liner (drawing BU650B-SL) is constructed of ¼" mild steel plate, as a minimum, filled with lead or lead equivalent. It is sealed in a fully welded containment. Approximate dimensions are 36" high by 30" diameter with a taper on one end with a center cavity for sealed sources. The shield liner closure bolts are 5/8" – 11 UNC, Grade 5.

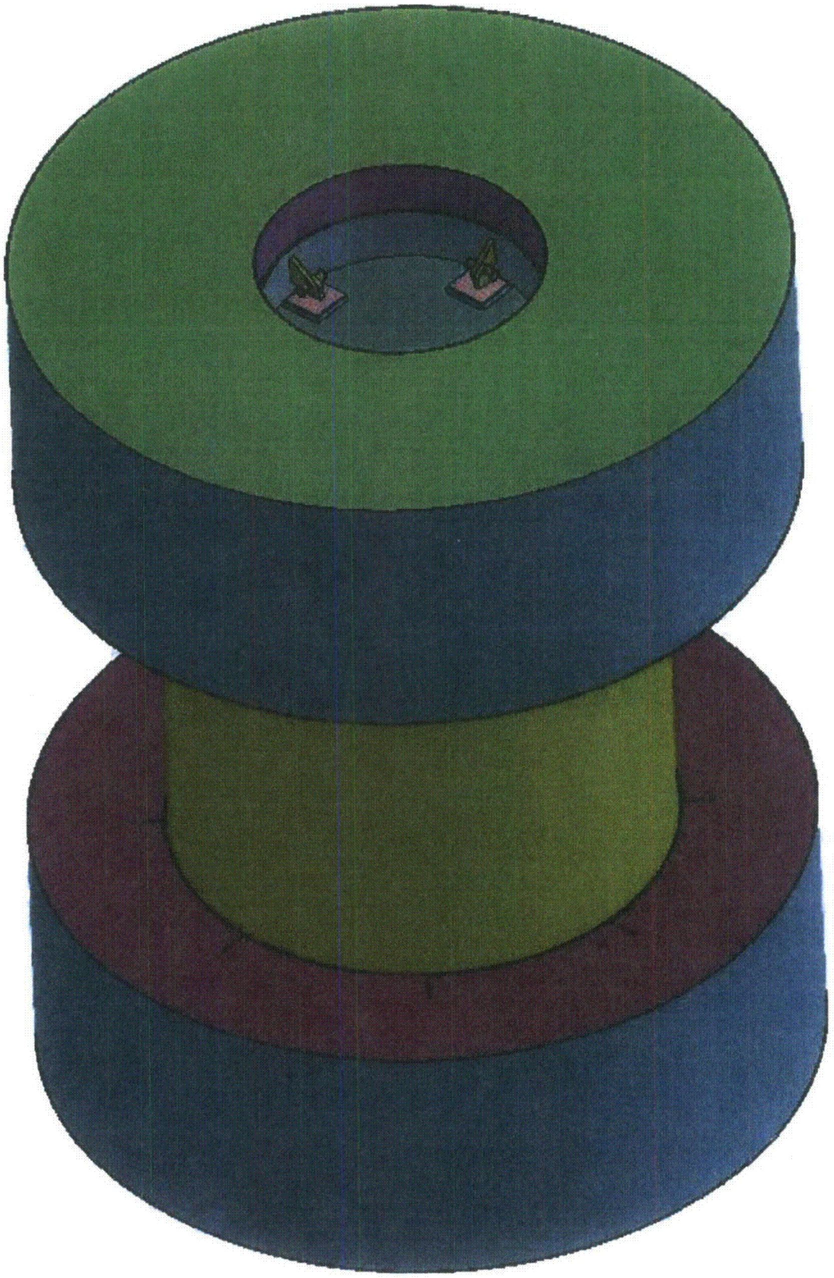

Figure 1: Assembled JL Shepherd & Associates BU650B Packaging (unmeshed)

BU650B COMPONENT WEIGHTS AND MATERIAL MODELS

Below are the model item numbers, descriptions, material properties used, total mass (lbf-s^2/in) of components (both upper and lower impact limiter components for example), and total weights in lbf. The unit conversion from mass to weight (or force) is 386 in/s^2.

GENERAL DESIGN AND COMPUTATION SHEET

DAC-P09YCW01-0001 000 00

Job LS-DYNA Impact Analyses of JL Shepherd & Associates Model BU650B Shipping Package	Date 4/19/12	Sheet 9 of 87
ESO No. P09YCW01	Computed by DLL D. L. Lowe	Checked by DEW D. E. Winder

BU650B LS-DYNA Model Mass / Weights				
Part	Description	Material	Mass in Model	Total Weight (lb)
1	Cask Body Outside Btm Plate	304 SS	0.564667000	217.96
2	Cask Body Inside Btm Plate	304 SS	0.361407000	139.50
3	Cask Body Inside Btm Plt Ext Lip	304 SS	0.037044200	14.30
4	Cask Body Outer Cyl Wall	304 SS	2.489770000	961.05
5	Cask Body Inner Cyl Wall	304 SS	1.816070000	701.00
6	Cask Body Top Closure Ring	304 SS	0.217937000	84.12
8	Cask Bolts - Welded Nuts	316L SS	0.040923900	15.80
10	Cask Bolts - Outer	316L SS	0.018457600	7.12
12	Cask Washers	316L SS	0.002560640	0.99
13	Cask Body Kaolite	Kaolite 1600	1.216810000	469.69
25	Cask Lid Top Bolting Flange	304 SS	0.258422000	99.75
26	Cask Lid Middle Plate	304 SS	0.321283000	124.02
27	Cask Lid Outside Cyl Wall	304 SS	0.029613000	11.43
28	Cask Lid Inside Cyl Wall	304 SS	0.081426000	31.43
29	Cask Lid Top Plate	304 SS	0.193902000	74.85
30	Cask Lid Outside Cyl Wall w/Weld	304 SS	0.003357470	1.30
31	Cask Lid Btm Inside Plate	304 SS	0.346082000	133.59
32	Cask Lid Inside Cyl with Weld	304 SS	0.006346150	2.45
33	Inside Shoring	304 SS	0.498215000	192.31
45	Impact Limiter Shell Upper Horiz Flat	304 SS	0.333257000	128.64
47	Impact Limiter Shell Inside Horiz Flat	304 SS	0.171201000	66.08
49	Impact Limiter Shell Inside Mid Cyl	304 SS	0.311455000	120.22
51	Impact Limiter Shell Inner	304 SS	0.124960000	48.23
53	Impact Limiter Shell Outer Cyl	304 SS	0.812105000	313.47
55	Impact Limiter Shell Outer Flat	304 SS	0.504454000	194.72
57	Impact Limiter Shell Inner Angle	304 SS	0.353428000	136.42
63	Impact Limiter Foam	GP FR-3712	2.178560000	840.92
70	Impact Limiter Lifting Ring	304 SS	0.148972000	57.50
72	Impact Limiter Bolting Lugs	304 SS	0.012352300	4.77
73	Impact Limiter Attachment Pins	304 SS	0.005871020	2.27
76	Shield Liner #1 Shell	AISI 1010 CS	0.886870000	342.33
91	Shield Liner #1 Body Lead	Lead	15.467200000	5970.34
100	Shield Liner #1 Lid Shell	AISI 1010 CS	0.085146100	32.87
104	Shield Liner #1 Lid Lead	Lead	0.894018000	345.09
105	Content In Shield Liner #1	304 SS	0.064500600	24.90
106	Shield Liner #1 Bolts	AISI 1020 CS	0.003972320	1.53
109	Shield Liner #1 Washers	AISI 1020 CS	0.000613711	0.24
111	Cask Body Lid Kaolite	Kaolite 1600	0.123484000	47.66
112	Cask Body Mounting Brackets	304 SS	0.043602100	16.83
113	Cask Body Mounting Lugs	304 SS	0.008828060	3.41
114	Cask Body Mounting Plate Welds	304 SS	0.003750190	1.45
118	Unyielding Impact Surface	Rigid Mat	0.004999980	1.93
119	Cask Bolts - Core Volume	316L SS	0.004056920	1.57
121	Shield Liner Bolts Core Volume	AISI 1020 CS	0.000514232	0.20
124	Shield Liner Impact Plt - Protect Bolts	304 SS	0.054417200	21.01
			Empty Cask Body Weight Including Impact Limiters	**5074.52**
			Shield Liner #1 Empty Weight w/Impact Plate	**6713.60**
			Shoring Weight	**192.31**
			Content Weight	**24.90**
			Total Cask, Shield Liner #1, Content, Shoring	**12005.33**

The LS-DYNA power law plasticity model (*MAT_POWER_LAW_PLASTICITY) is used for some of the components. This is an isotropic plasticity model with rate effects which uses the power law hardening rule. The model equation is as follows;

$$\sigma = K\varepsilon^{m}$$

The values for the strength coefficient, *K*, and hardening coefficient, *m*, are given below along with the other properties used in the LS-DYNA model. These values were obtained from the STRAIN software database (Reference 3);

304 Stainless Steel (bar annealed)
Poisson's ratio – 0.29
Mass Density – 7.5130E-4 lb-sec^2/in^4
Material Density – 0.29 lb/in^3
Young's Modulus – 2.81E7 psi
Strength Coefficient (*K*) – 162,738 psi
Hardening Exponent (*m*) – 0.27208
Elongation at Failure (%) – 57%
Reduction in Area (%) – 67%

316L Stainless Steel
Poisson's ratio – 0.29
Mass Density – 7.5130E-4 lb-sec^2/in^4
Material Density – 0.29 lb/in^3
Young's Modulus – 2.8E7 psi
Strength Coefficient (*K*) – 135,156 psi
Hardening Exponent (*m*) – 0.22634
Elongation at Failure (%) – 55%

AISI 1010 Carbon Steel
Poisson's ratio – 0.29
Mass Density – 7.3316E-4 lb-sec^2/in^4
Material Density – 0.283 lb/in^3
Young's Modulus – 3.0E7 psi
Strength Coefficient (*K*) – 77,364 psi
Hardening Exponent (*m*) – 0.18572
Elongation at Failure (%) – 28%

AISI 1020 Carbon Steel (hardened)
Poisson's ratio – 0.29
Mass Density – 7.3575E-4 lb-sec^2/in^4
Material Density – 0.284 lb/in^3
Young's Modulus – 3.0E7 psi
Strength Coefficient (*K*) – 156,749 psi
Hardening Exponent (*m*) – 0.1244
Elongation at Failure (%) – 6%

The LS-DYNA isotropic elastic plastic model (*MAT_ISOTROPIC_ELASTIC_PLASTIC) was used to model the lead in the shield liner with the following properties;

Lead
Mass Density – 1.0645E-3 lb-sec^2/in^4
Material Density – 0.4109 lb/in^3
Shear Modulus – 7.2519E5 psi
Yield Stress – 1,740.45 psi
Plastic Hardening Modulus – 8,702.26 psi
Bulk Modulus, *K* – 4.206E6 psi

The Kaolite 1600 is modeled using the LS-DYNA honeycomb material (*MAT_HONEYCOMB) with the following properties;

Kaolite 1600
Mass Density – 3.3583E-05 lb-sec^2/in^4
Young's Modulus – 1.0E6 psi
Poisson's ratio – 0.01
Fully Compacted Yield Stress – 40,000 psi
Fully Compacted Relative Volume – 0.20
Elastic Modulus (uncompressed) – 14,811 psi
Shear Modulus (uncompressed) – 7,405 psi

The kaolite values of relative volume (ratio of the current volume to the initial volume) versus the average stress (psi) are detailed below (the non-zero stress value at 0.00 relative volume is to ensure a stable model);

Relative Volume	Average stress (psi)
0.00	148
0.01	148
0.10	248
0.20	317
0.30	396
0.40	523
0.50	797
0.55	1,079
0.60	1,553
0.65	2,500
0.70	5,000
0.75	10,000
0.775	20,000
0.79	30,000
0.80	40,000

The General Plastics Last-A-Foam, FR-3712 (12 lbs/ft^3), is modeled using the LS-DYNA honeycomb material model (*MAT_HONEYCOMB) with the following properties;

FR-3712 (12 lbs/ft^3)
Mass Density – 1.797E-05 lb-sec^2/in^4
Young's Modulus – 6.0E5 psi
Poisson's ratio – 0.01
Fully Compacted Yield Stress – 10,000 psi
Fully Compacted Relative Volume – 0.15
Elastic Modulus (uncompressed) for E_{aau} and E_{bbu} – 12,339 psi
Elastic Modulus (uncompressed) for E_{ccu} – 13,889 psi
Shear Modulus (uncompressed) for G_{abu} and G_{bcu} – 3629.0 psi
Shear Modulus (uncompressed) for G_{abu} and G_{bcu} – 3760.0 psi

The **FR-3712 (transverse direction)** values of relative volume (ratio of the current volume to the initial volume) versus the average stress (psi) are detailed below (the non-zero stress value at 0.00 relative volume is to ensure a stable model);

Relative Volume	Average stress (psi)
0.00	459
0.10	459
0.20	463
0.30	483
0.40	518
0.50	622
0.60	854
0.65	1,110
0.70	1,447
0.75	2,430
0.80	4,031
0.85	10,000

The **FR-3712 (parallel direction)** values of relative volume (ratio of the current volume to the initial volume) versus the average stress (psi) are detailed below (the non-zero stress value at 0.00 relative volume is to ensure a stable model);

Relative Volume	Average stress (psi)
0.00	465
0.10	465
0.20	471
0.30	492
0.40	526
0.50	628
0.60	856
0.65	1,099
0.70	1,407
0.75	2,478
0.80	4,093
0.85	10,000

BU650B PACKAGING INDIVIDUAL COMPONENT DESCRIPTIONS

BU650B Main Body and Components

The assembled BU650B body with lid in place is shown in Figure 2 through Figure 6. The BU650B body shell components nodes at the interfaces were created to be coincident and these nodes are all allowed to merge completely since all welds are to be full penetration during fabrication. The main body inner spaces are filled with Kaolite 1600 and these two differing materials of the main body are not allowed to merge into one component at the nodes. Since the main body closure nuts are to be welded to the inside surface of the body top plate and located in the kaolite region, these welded nuts and top plate nodes are coincident and allowed to merge together as one component. The body closure bolts and closure nut nodes are coincident and are also allowed to merge. However, the closure washers are not allowed to merge with any other component.

The upper attachment lug, mounting plates and welds are used to secure the impact limiters to the BU650B body. The body lugs and mounting plates attachment nodes were created as coincident and were allowed to merge because the welds at these locations are full penetration. However, the nodes of the mounting plates and the cask body upper and bottom outside plates were not allowed to merge. The welds are used to attach the mounting plates and upper and lower outside body plates at the corresponding coincident nodes.

Both the main body bolts (quantity 24) and the inner shield liner bolts (quantity 8) were created out of two components, the outer bolt material and the inner center core volume. The bolts were created in this manner to distinguish between the outer bolt surfaces which might show high strains / stresses due to localized impacts and contacts and the inner core volumes which can more accurately capture the actual plastic strains. Analyzing the inner core volumes can more accurately predict bolt failure. The coincident nodes of both the inner and outer bolt volumes were allowed to merge to create one component with the same material properties. This method of modeling creation allows for easier data extraction between the two regions during post processing of modeling results.

The BU650B main body bolts are ¾" – 10 UNC and are 316L SS. The bolt head outside diameter is 1.25 inch and thickness is 0.5 inch. The washers (316L SS) dimensions are 1.5 inch outside diameter, 0.875 inch inside diameter, and 0.125 inch thick. The preload bolt stresses due to the torque (100 ft-lbs) are incorporated into the model. The effective bolt stress area first was calculated from the following equation;

$$Area_{STRESS} = \left(\frac{\pi}{4}\right)\left(\frac{d_m + d_p}{2}\right)^2 \quad \text{where}$$

$$d_p = (bolt\,diameter, d) - (0.649519)(P)$$

$$d_m = (bolt\,diameter, d) - (1.299038)(P)$$

$$P = 1/(bolt\,thread\,per\,inch)$$

The effective bolt stress area which was used in the model for the ¾" – 10 UNC bolts is calculated as follows;

$$P = 1/(bolt\,thread\,per\,inch) = 1/10 = 0.1$$

$$d_p = (bolt\,diameter, d) - (0.649519)(P) = (0.75) - (0.649519)(0.1) = 0.6850481$$
$$d_m = (bolt\,diameter, d) - (1.299038)(P) = (0.75) - (1.299038)(0.1) = 0.6200962$$

$$Area_{STRESS} = \left(\frac{\pi}{4}\right)\left(\frac{d_m + d_p}{2}\right)^2 = \left(\frac{\pi}{4}\right)\left(\frac{0.6200962 + 0.6850481}{2}\right)^2 = 0.334462\,in^2$$

This effective stress area results in an effective bolt diameter of the ¾" – 10 UNC bolt of 0.6526 inch. Using this smaller stress area and bolt dimensions rather than the nominal bolt dimensions results in a more accurate bolt analyses. Each bolt preload force is then calculated from the following equation;

$$Torque = (K)(preload\ Force)(Bolt\ Diameter)$$

Where K is a torqueing constant typically assumed to be 0.2. Thus, the ¾" – 10 UNC bolt preload resulting from a torque of 100 ft-lbs is calculated as follows;

$$preload = (100\,ft - lb)(12\,in/1\,ft)/(0.2)(0.75\,in) = 8{,}000\,lbs/bolt$$

And the preload bolt stress which is programming into the model for each bolt is calculated as follows;

$$Stress_{3/4"-10UNC\ Bolt} = (8{,}000\,lbs)/(0.3344621\,in^2) = 23{,}919\,psi$$

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P09YCW01	DLL D. L. Lowe	DEW D. E. Winder

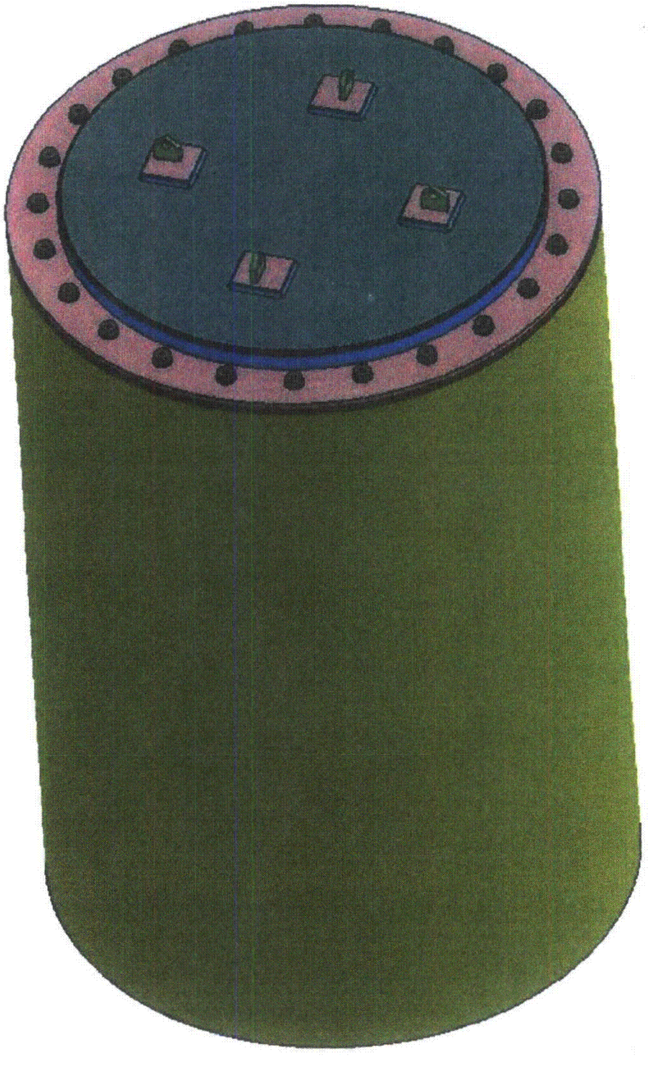

Figure 2: BU650B Body with Lid; Assembled

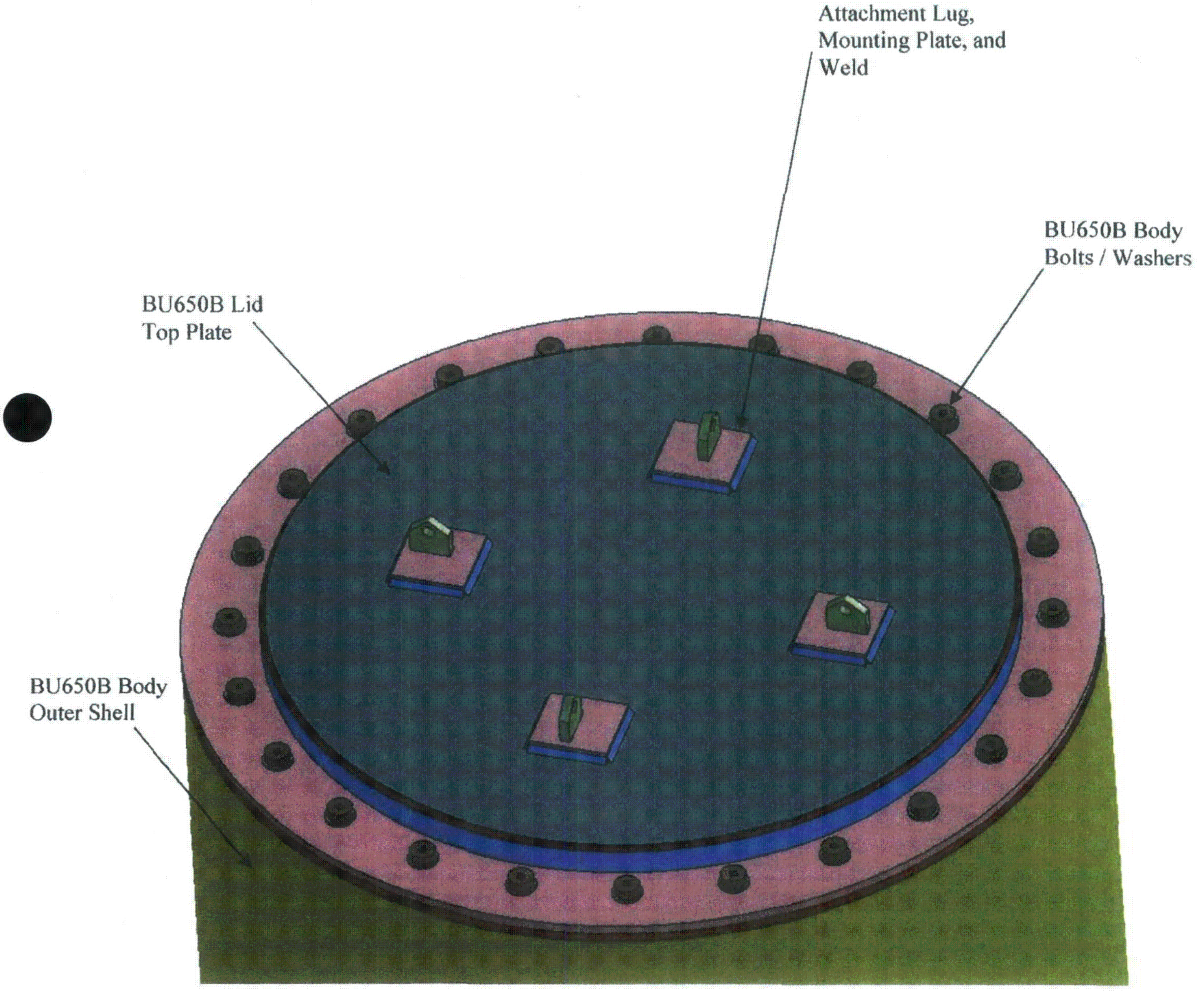

Figure 3: BU650B Body and Lid; Unmeshed

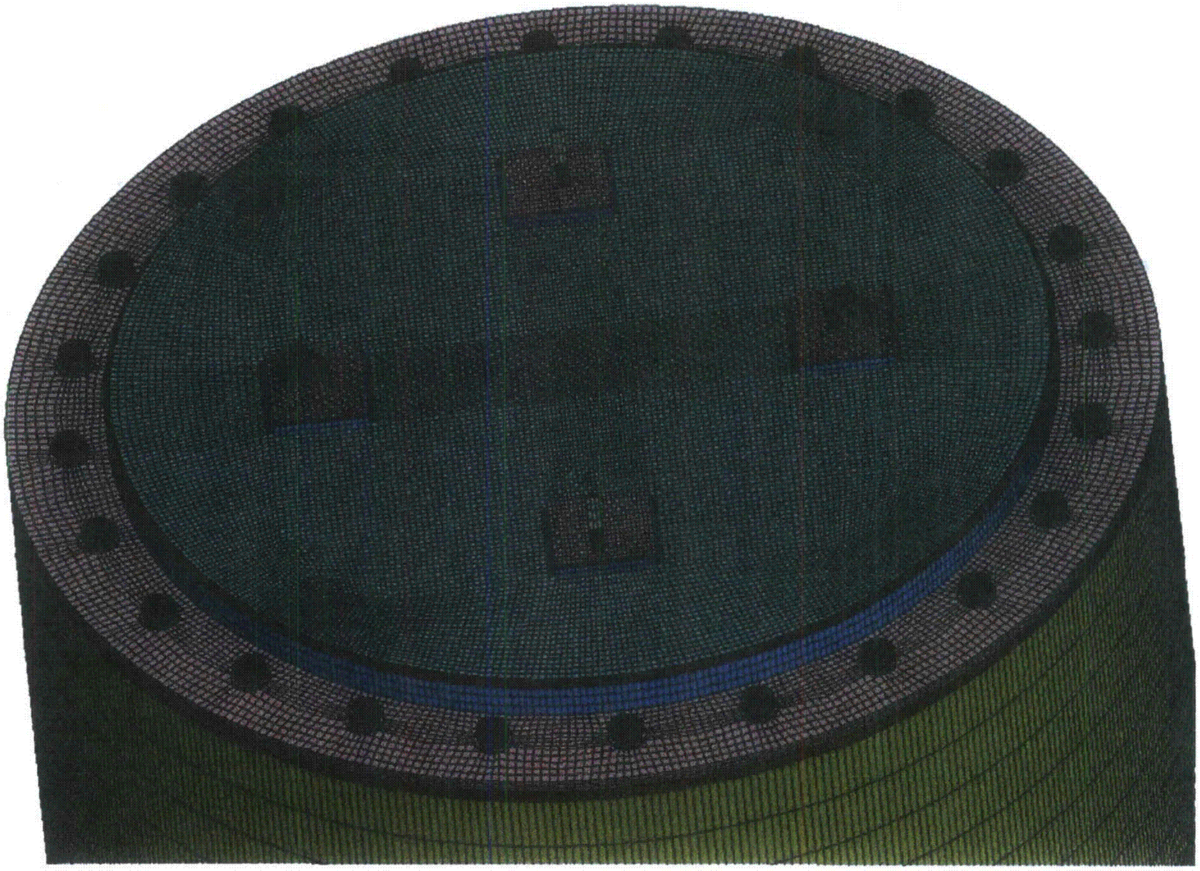

Figure 4: BU650B Body, Lid, and Closure Bolts / Washers; Meshed

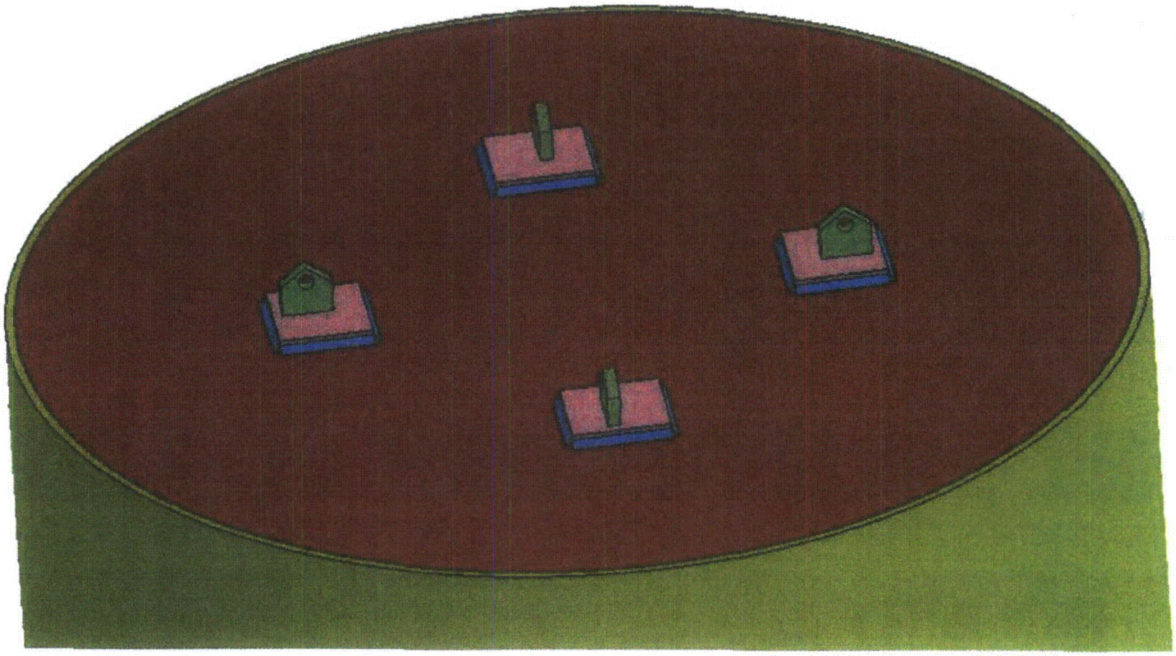

Figure 5: BU650B Body Bottom View; Unmeshed

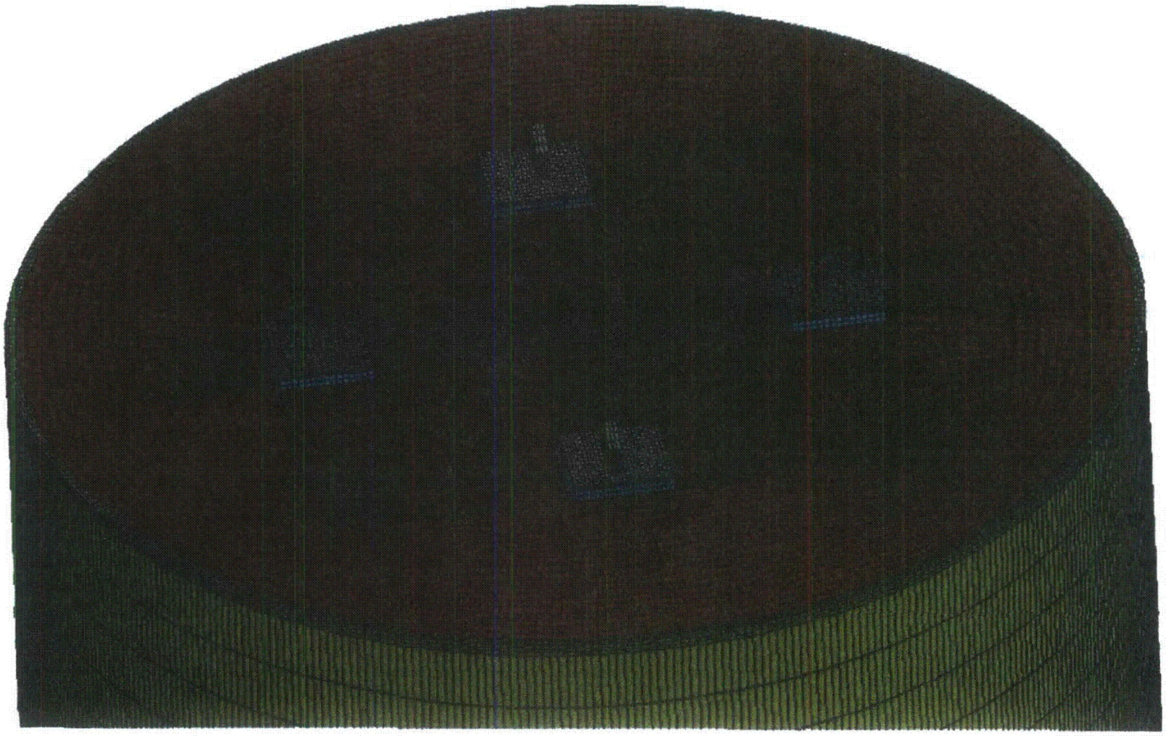

Figure 6: BU650B Body Bottom View; Meshed

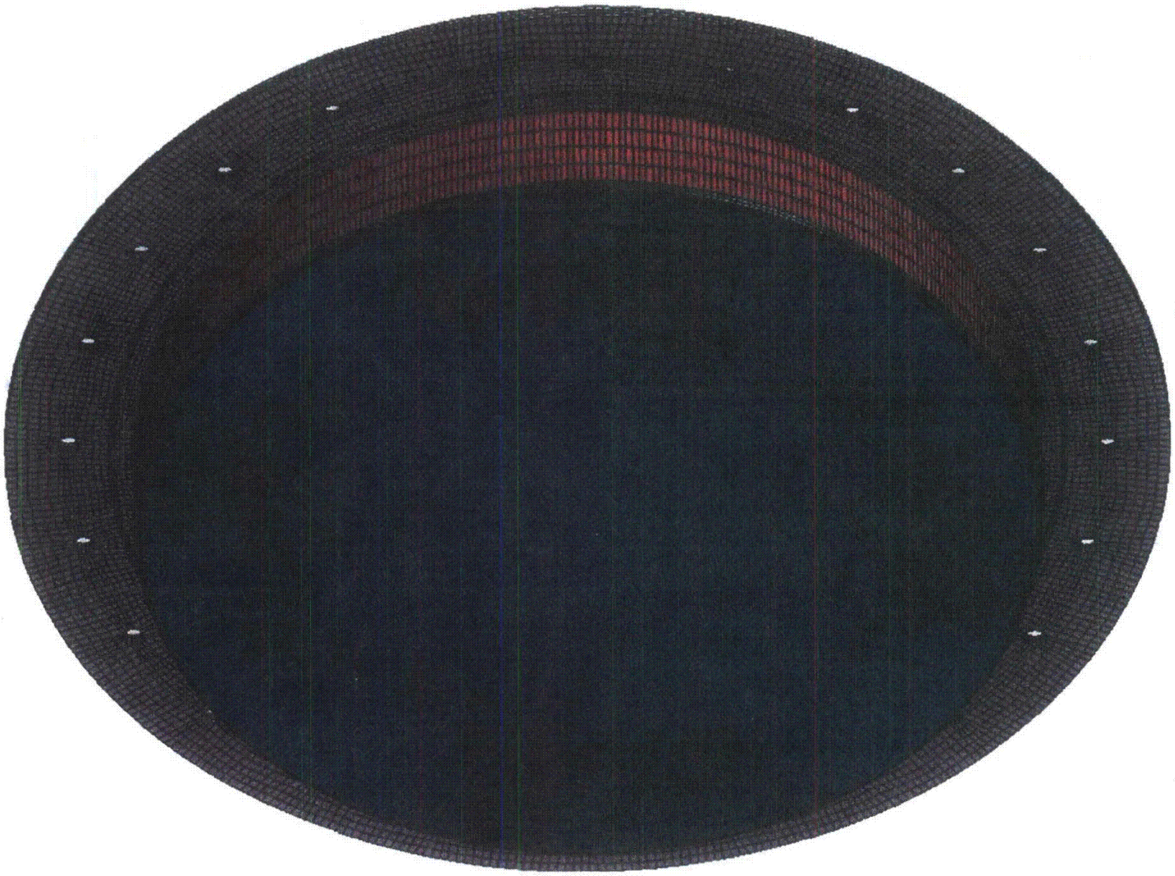

Figure 7: BU650B Lid Bottom View; Meshed

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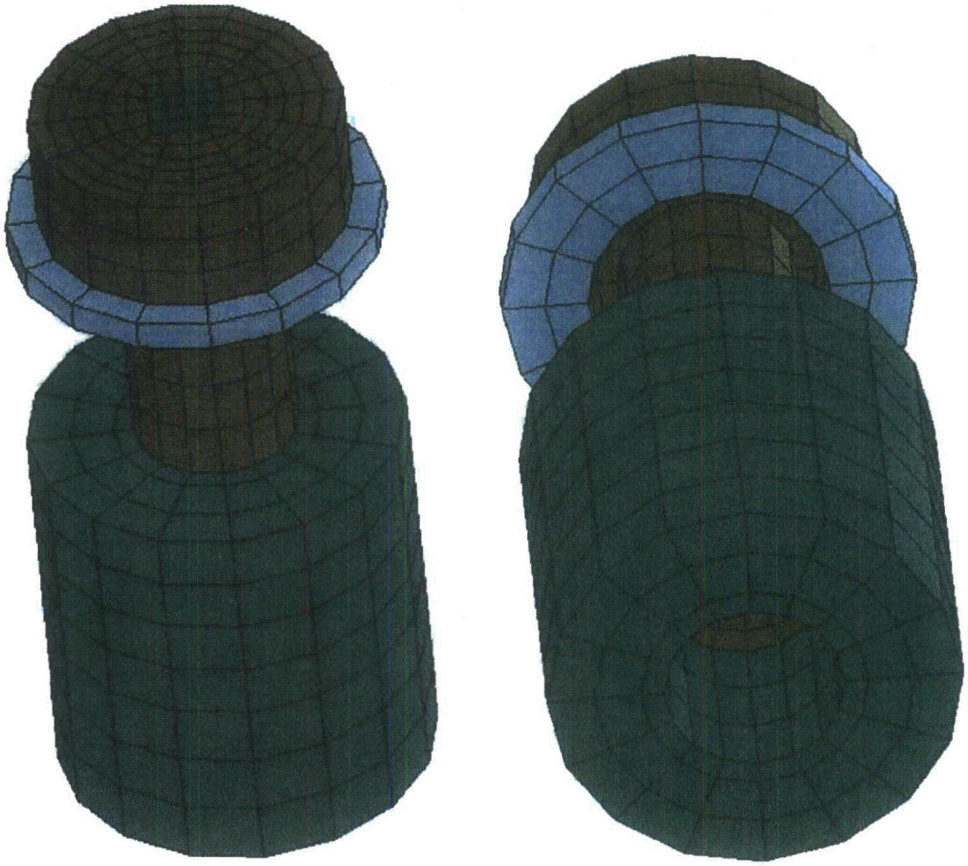

Figure 8: BU650B Body Bolt (Outer and Core Volumes), Welded Nut and Washer

The Impact Limiter Outer Shell, Inner Angle Bracing, Foam, Lifting Ring, and Attachment Lugs

Figures 9 through 16 illustrate various components of both the upper and lower BU650B impact limiters. The coincident nodes of the outer sheet metal surfaces were allowed to fully merge. The inner angle bracing coincident nodes were also allowed to fully merge as shown in Figures 15 and 16. This was allowed because the angle pieces are welded to the impact limiter sheet metal and are also held in place by the General Dynamics FR-3712 foam. The inner lifting ring and the innermost vertical cylinder of the impact limiters were allowed to also merge since these are fully welded to one another around their circumference, both top and bottom. The attachment pins (hitch pins) are identified as McMaster Carr #94563A913 and are 18-8 Stainless Steel, 5/8" diameter pins with 3" usable length. Because of the bent ends and cotter pin securement ends, to ease modeling creation, small outer 'keeper' plates were added to keep the pins from falling out either side of the attachment lugs (see Figure 13). These pin 'keeper' plates were found to not have any structural effect to the interaction between the attachment lugs. The impact foam and attachment pins are not allowed to merge with the nodes of any other components. Due to the full penetration welds between the lifting ring and attachment lugs of the impact limiters, their coincident nodes were allowed to merge.

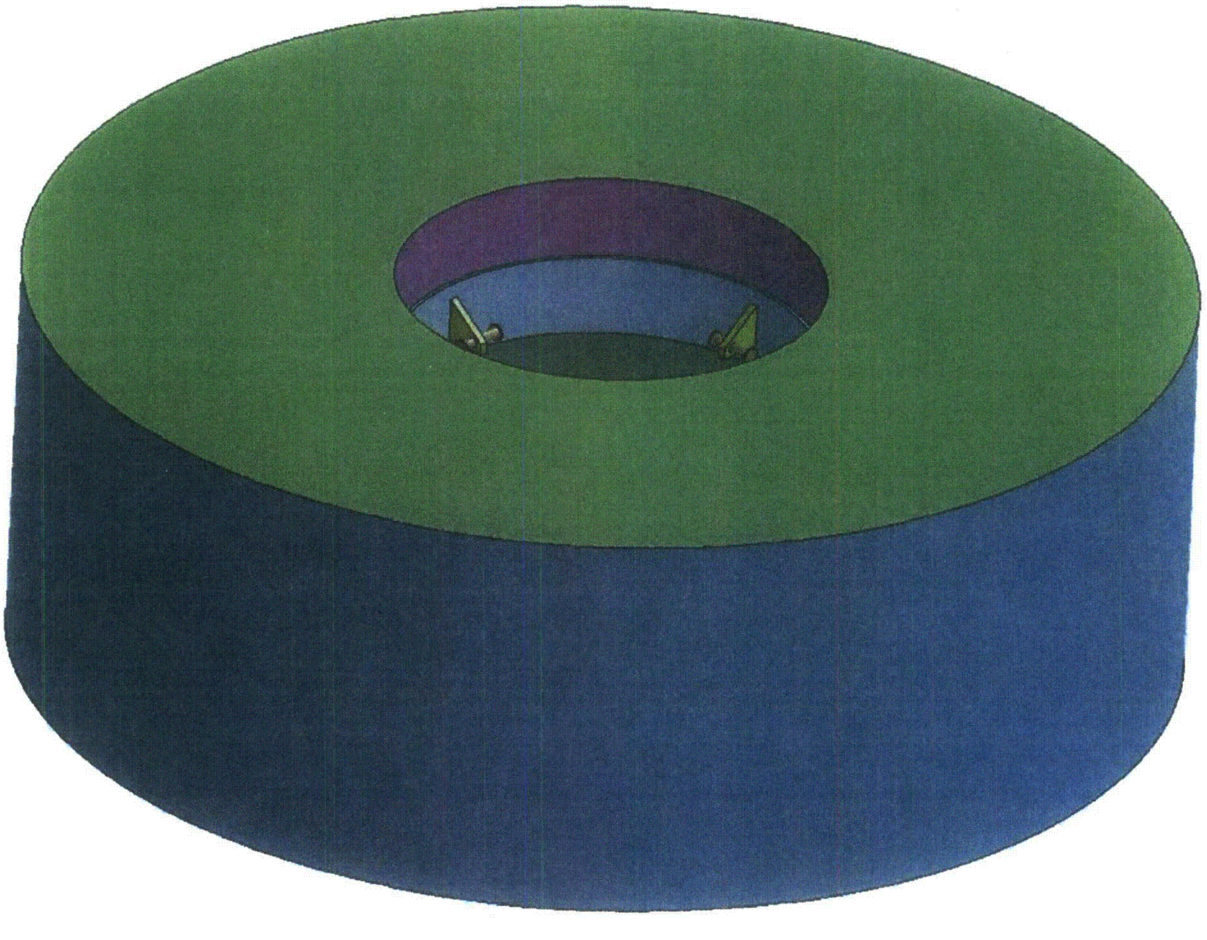

Figure 9: BU650B Impact Limiter with Inner Lifting Ring, Attachment Lugs and Pins; Unmeshed

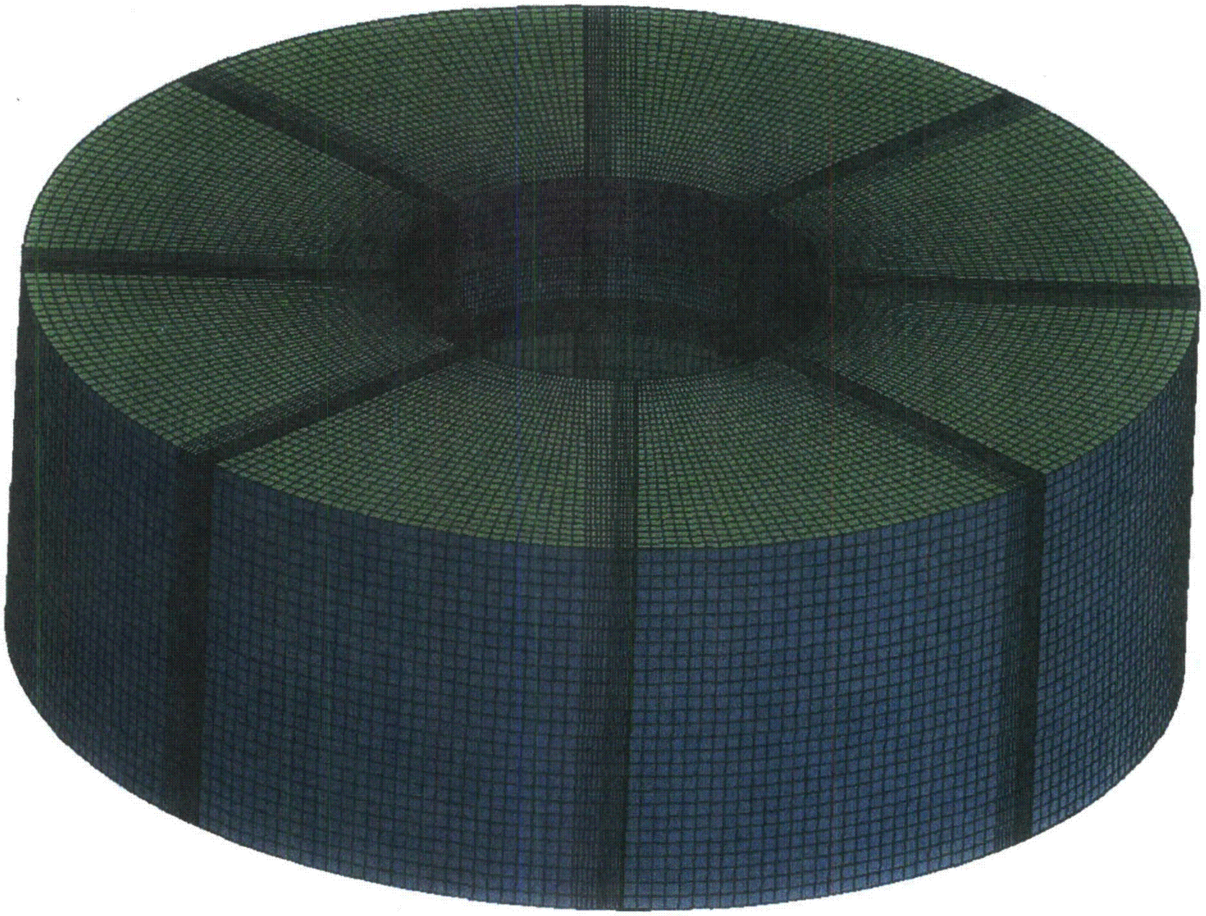

Figure 10: BU650B Impact Limiter with Lifting Ring, Lugs and Attachment Pins; Meshed

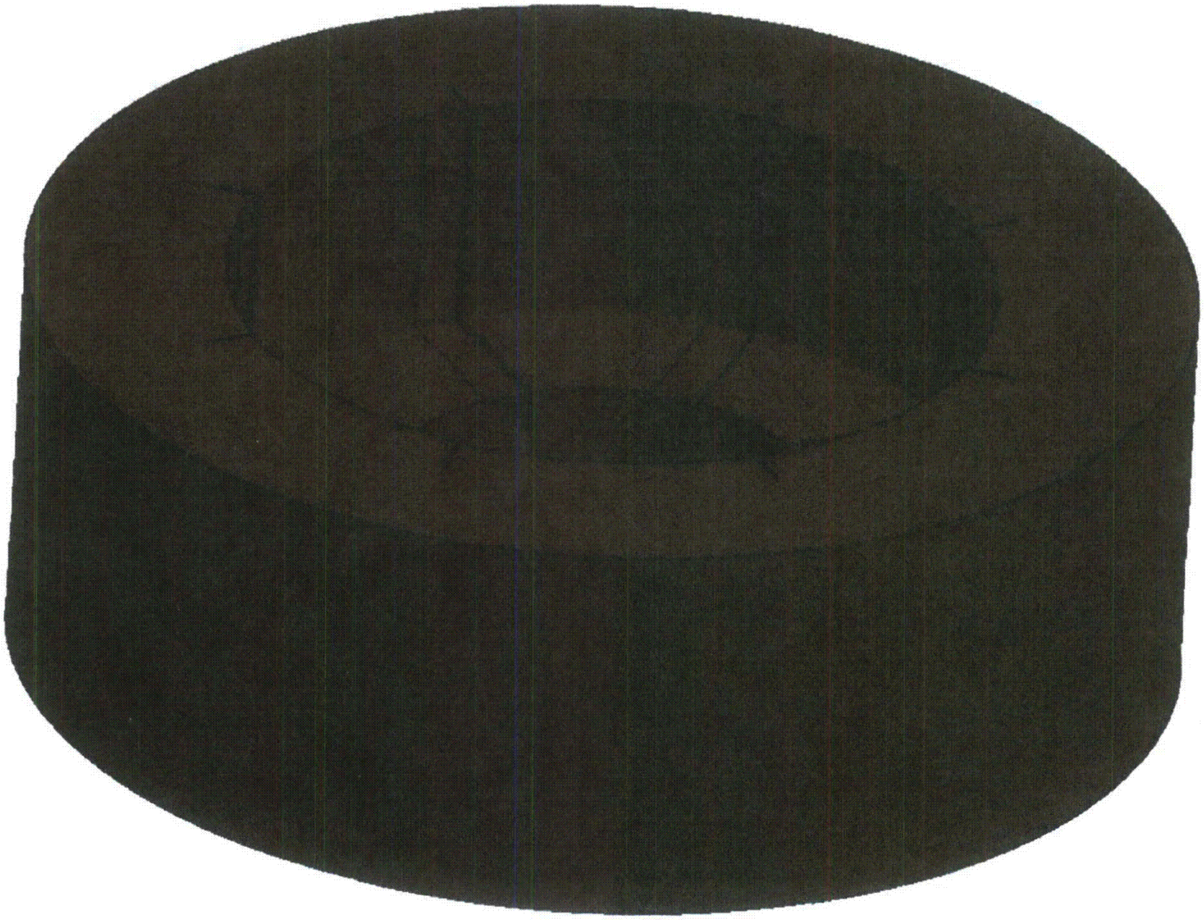

Figure 11: BU650B Impact Limiter Foam; Unmeshed

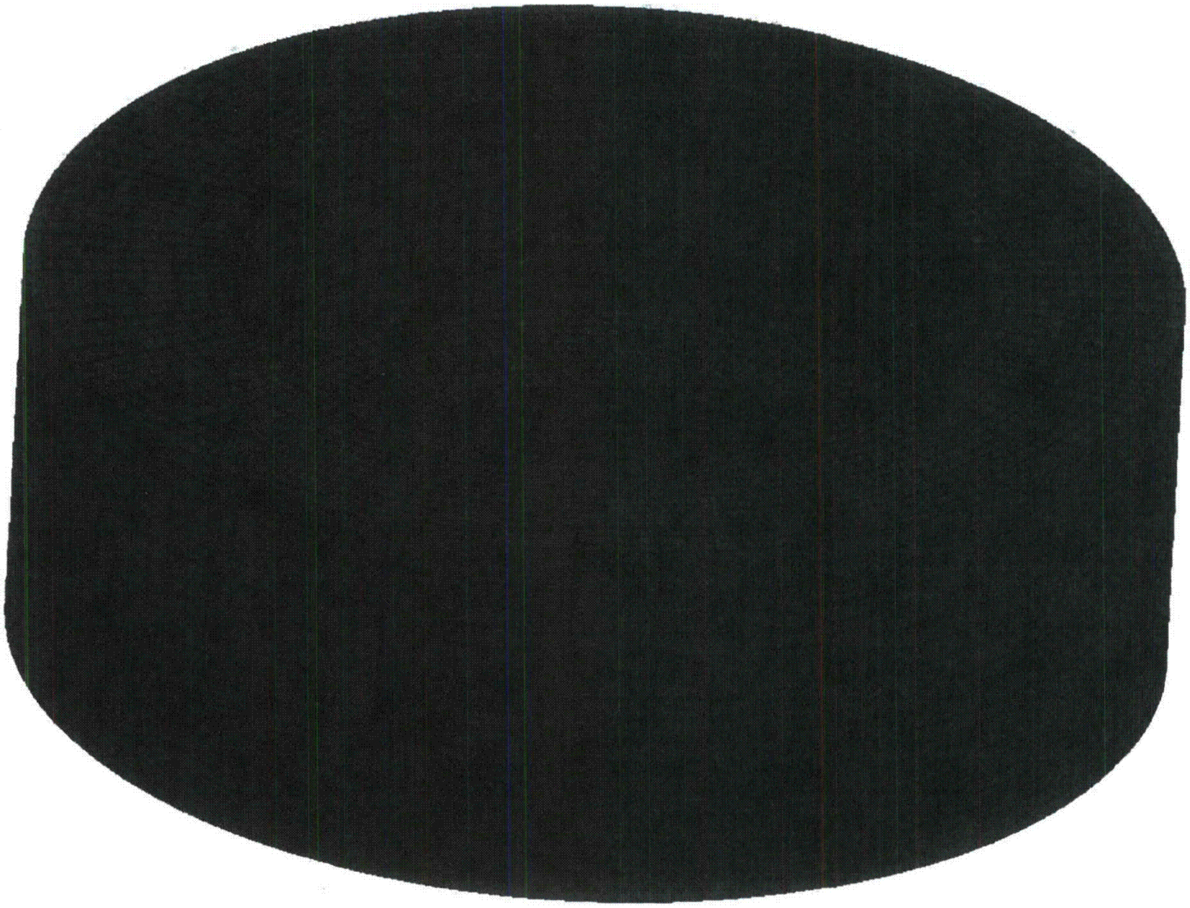

Figure 12: Impact Limiter Foam: Meshed

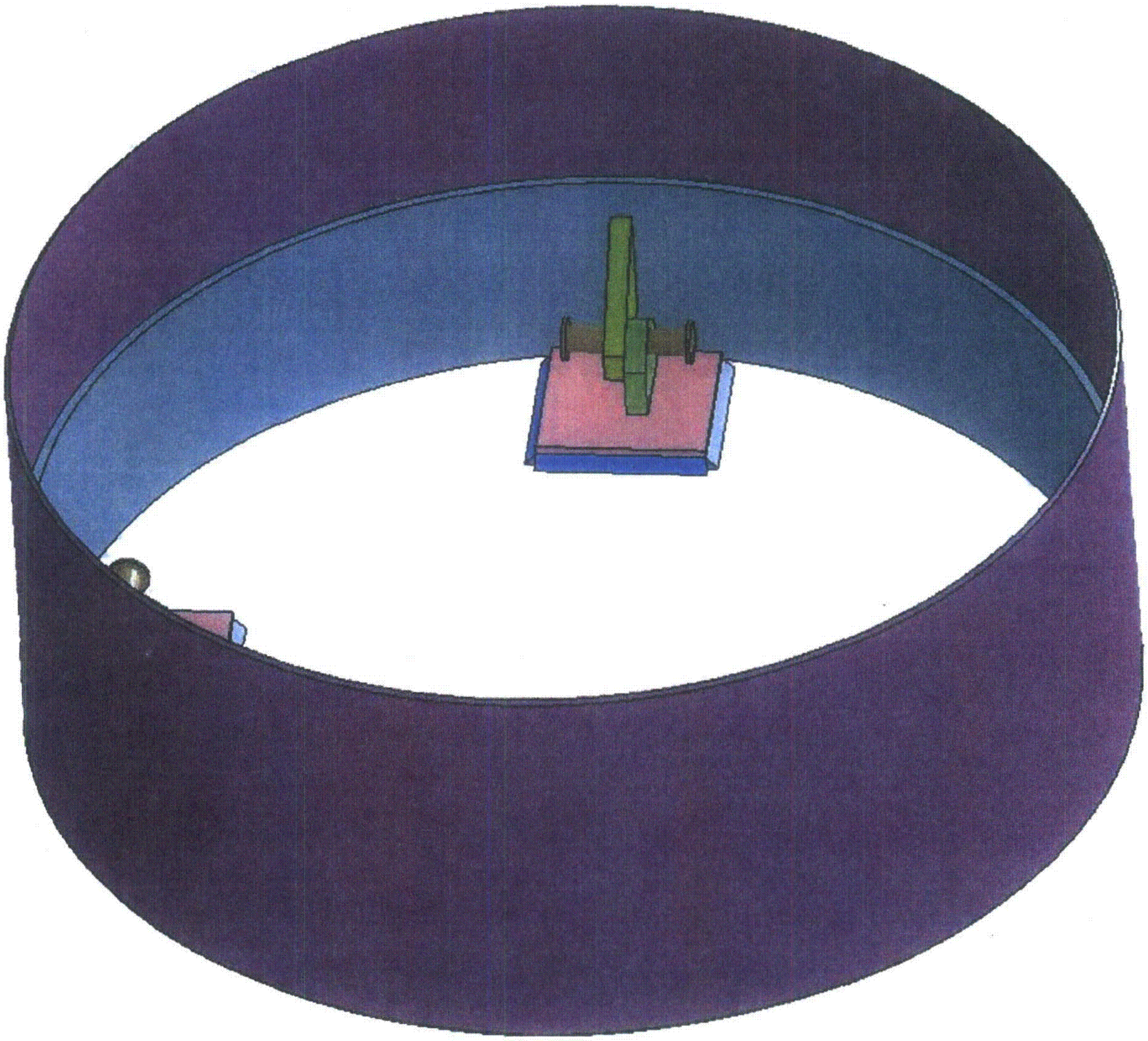

Figure 13: Impact Limiter Inner Shell, Lifting Ring, Attachment Lugs, Mounting Plates, Welds and Attachment Pins; Unmeshed

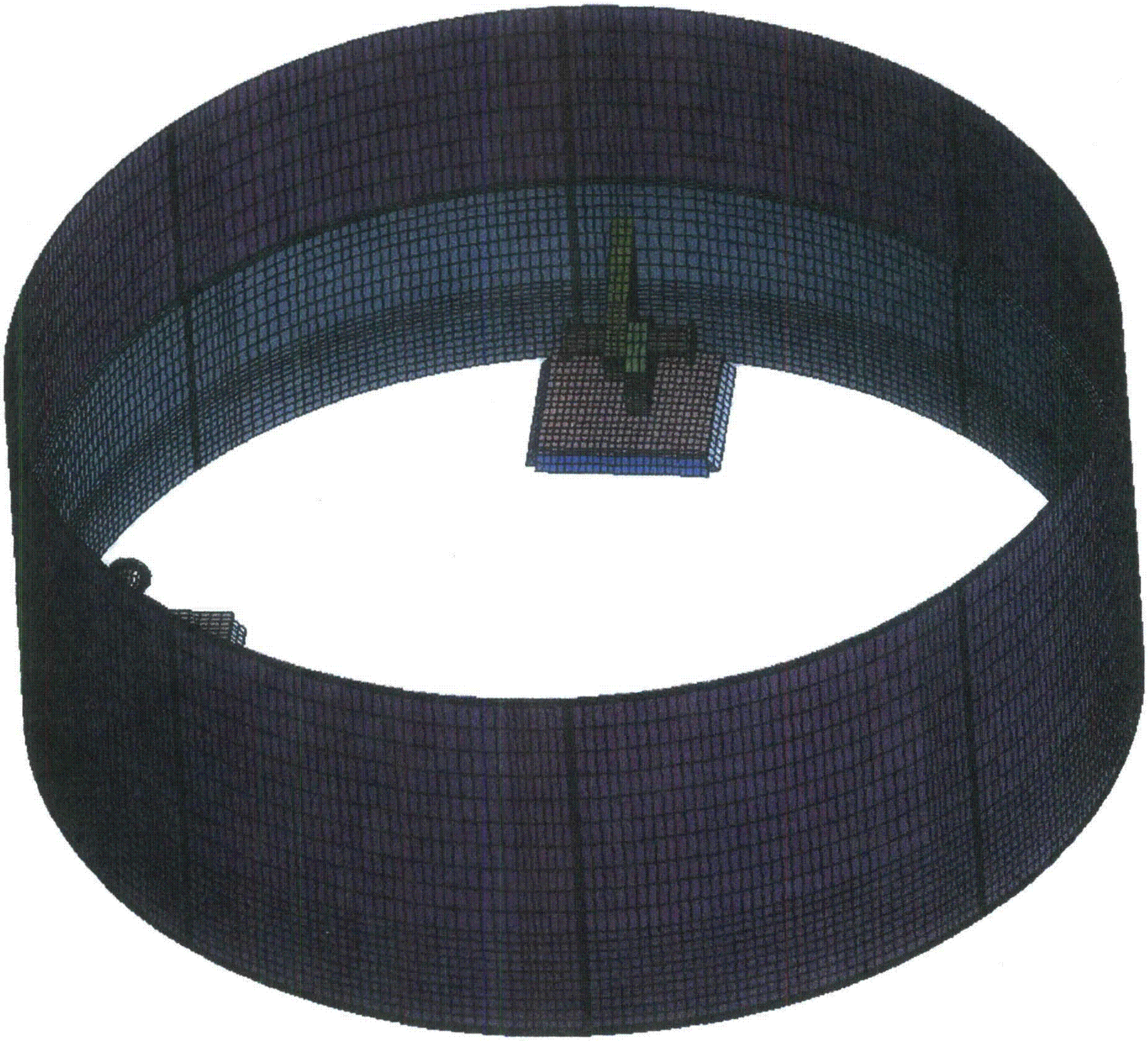

Figure 14: Impact Limiter Inner Shell, Lifting Ring, Attachment Lugs, Mounting Plates, Welds and Attachment Pins; Meshed

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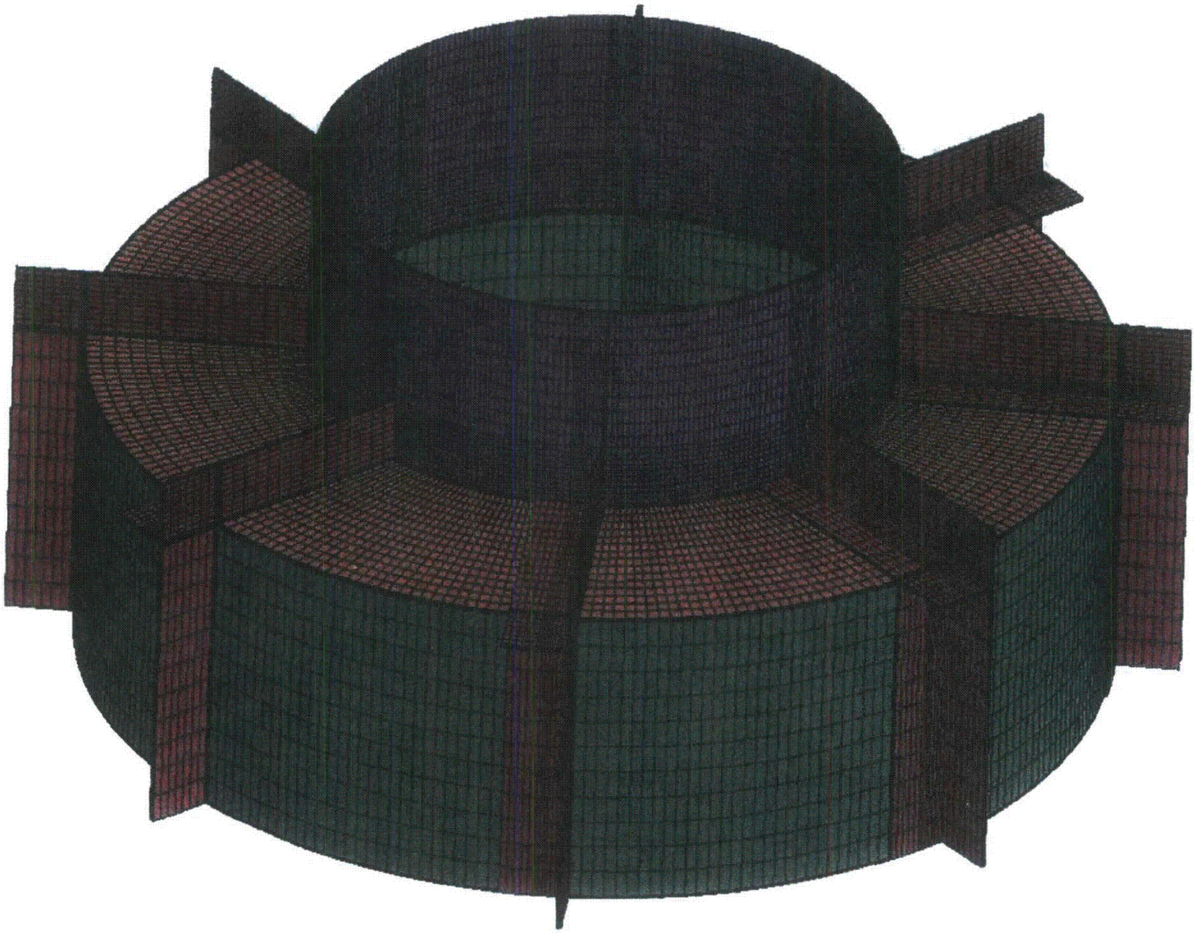

Figure 15: Impact Limiter Shell Portions and Inner Angle Bracing; Meshed

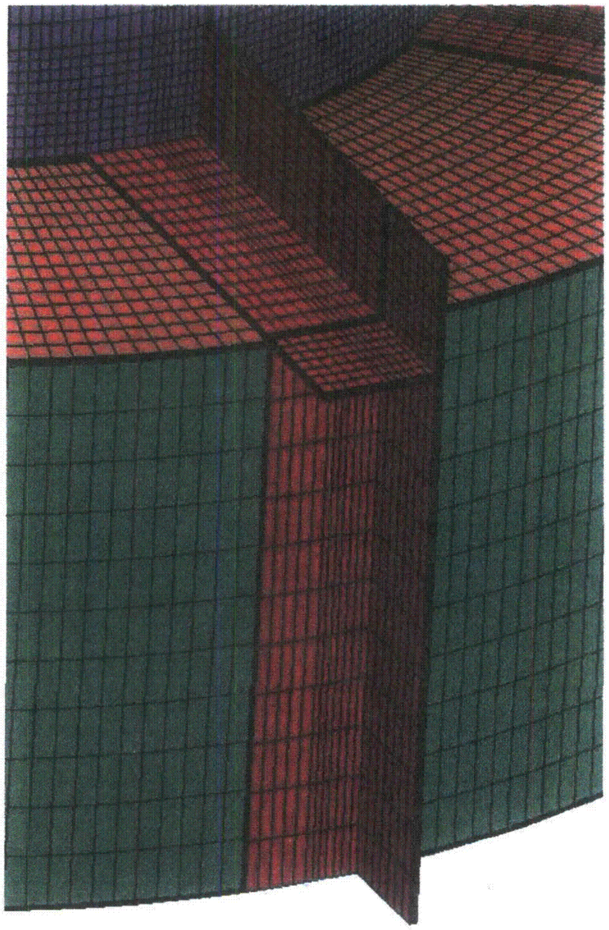

Figure 16: Impact Limiter Inner Angle Bracing Glued to Inner Shell; Meshed

SHIELD LINER SHELL, LEAD, BOLTS, WASHERS, AND BOLT-PROTECTING IMPACT PLATE

Figures 17 through 23 illustrate the various components of the internal (typical) Shield Liner and components (dwg BU650B-SL, Rev A). All outer shield liner shell walls were created as ¼" mild steel. The inner identified stainless steel material was changed to mild steel. The lower special plate had to be changed to an 8" x 8" cutout so it would fit inside the BU650B main body. Because of the difficulty in creating the FEA model of the lifting lug, the outer lug thickness is approximately 2.05" at the outside surface and reduces to approximately 1.2" at the inside surface near the bolting plate location.

Initial modeling results revealed high probability the shield liner bolts would fail because of their interaction with the internal shoring. This resulted in designing a bolt-protecting impact plate (see Figure

17 and 19) which would transmit the impact energy into the shield liner lid and body instead of through the bolts and was successful. As shown in Figure 19, the bolt-protecting impact plate has an upper ¾" thickness, an outside diameter of 13-5/8", an upper 9" diameter cutout, and an outer vertical lip extension which protrudes down 1.5" from the bottom of the upper plate. The outside lid total height is 2.25". Cutouts for the bolts were created to allow the impact plate to not interact with the bolt heads when shifting laterally with the shield liner lid.

The shield liner closure bolts are 5/8" – 11 UNC and are identified as Grade 5. The bolt head outside diameter is 1.0625 inch and thickness is 0.4375 inch. The washer dimensions are 1.5 inch outside diameter, 0.6875 inch inside diameter, and 0.125 inch thick. The preload bolt stresses due to the torque (50 ft-lbs) are incorporated into the model. The effective bolt stress area first was calculated from the following equation;

$$Area_{STRESS} = \left(\frac{\pi}{4}\right)\left(\frac{d_m + d_p}{2}\right)^2 \quad \text{where}$$

$$d_p = (bolt\ diameter, d) - (0.649519)(P)$$
$$d_m = (bolt\ diameter, d) - (1.299038)(P)$$
$$P = 1/(bolt\ thread\ per\ inch)$$

The effective bolt stress area is calculated as follows;

$$P = 1/(bolt\ thread\ per\ inch) = 1/11 = 0.0909$$
$$d_p = (bolt\ diameter, d) - (0.649519)(P) = (0.625) - (0.649519)(0.0909) = 0.5659529$$
$$d_m = (bolt\ diameter, d) - (1.299038)(P) = (0.625) - (1.299038)(0.0909) = 0.5069058$$

$$Area_{STRESS} = \left(\frac{\pi}{4}\right)\left(\frac{d_m + d_p}{2}\right)^2 = \left(\frac{\pi}{4}\right)\left(\frac{0.5659529 + 0.5069058}{2}\right)^2 = 0.2260034\, in^2$$

This effective stress area results in an effective bolt diameter of the 5/8" – 11 UNC bolt of 0.5364 inch. Each bolt preload force is then calculated from the following equation;

$$Torque = (K)(preload\ Force)(Bolt\ Diameter)$$

Where K is a torqueing constant typically assumed to be 0.2. Thus, the 5/8" – 11 UNC bolt preload resulting from a torque of 50 ft-lbs is calculated as follows;

$$\Pr eload = (50\, ft - lb)(12\, in/1\, ft)/(0.2)(0.625\, in) = 4{,}800\, lbs/bolt$$

The preload bolt stress which is programmed into the model for each bolt is calculated as follows;

$$Stress_{3/4"-10UNC\ Bolt} = (4{,}800\, lbs)/(0.2260034\, in^2) = 21{,}239\, psi$$

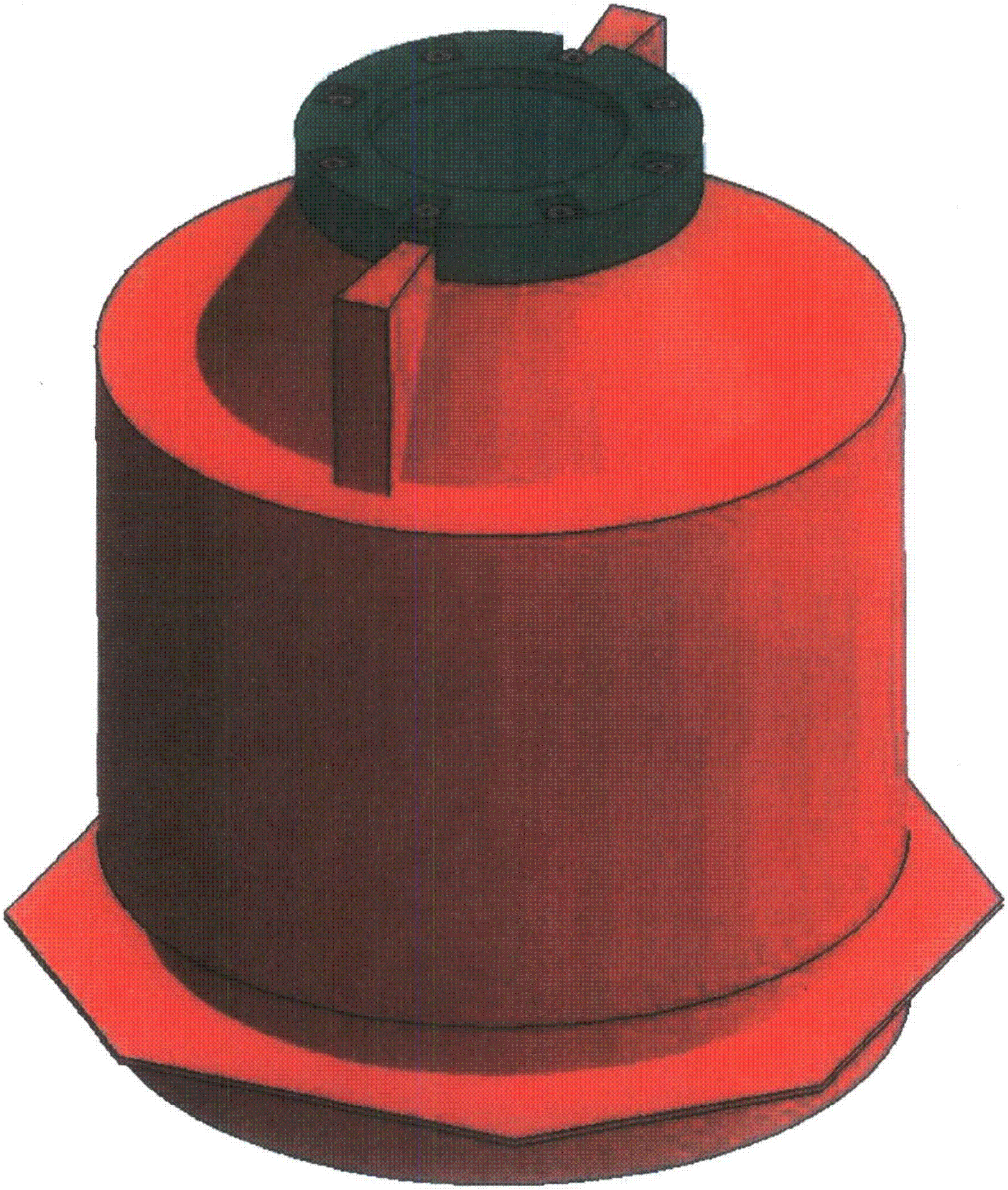

Figure 17: Shield Liner (Typical) with Bolt-Protecting Impact Plate; Unmeshed

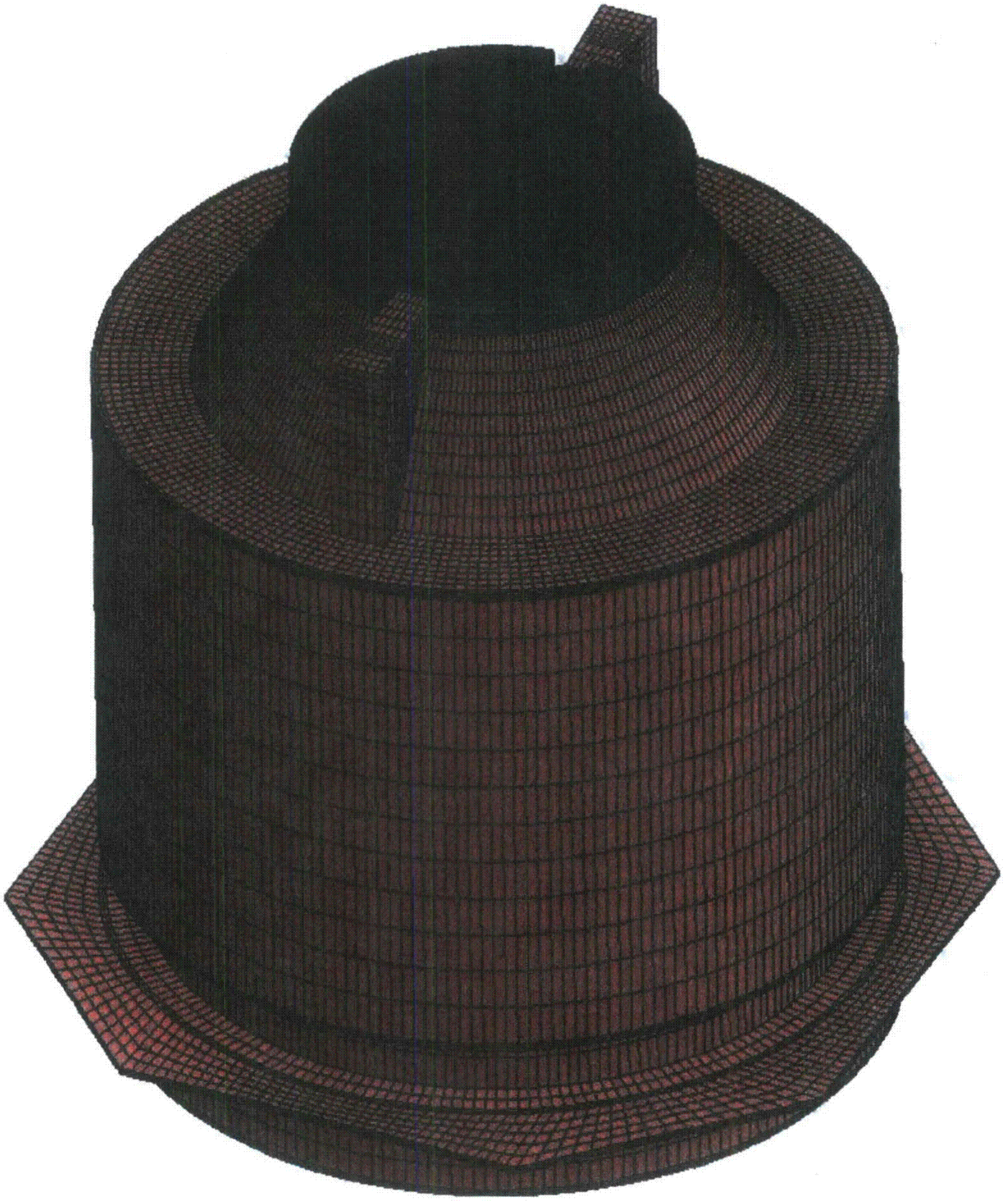

Figure 18: Shield Liner (Typical) with Bolt-Protecting Impact Plate; Meshed

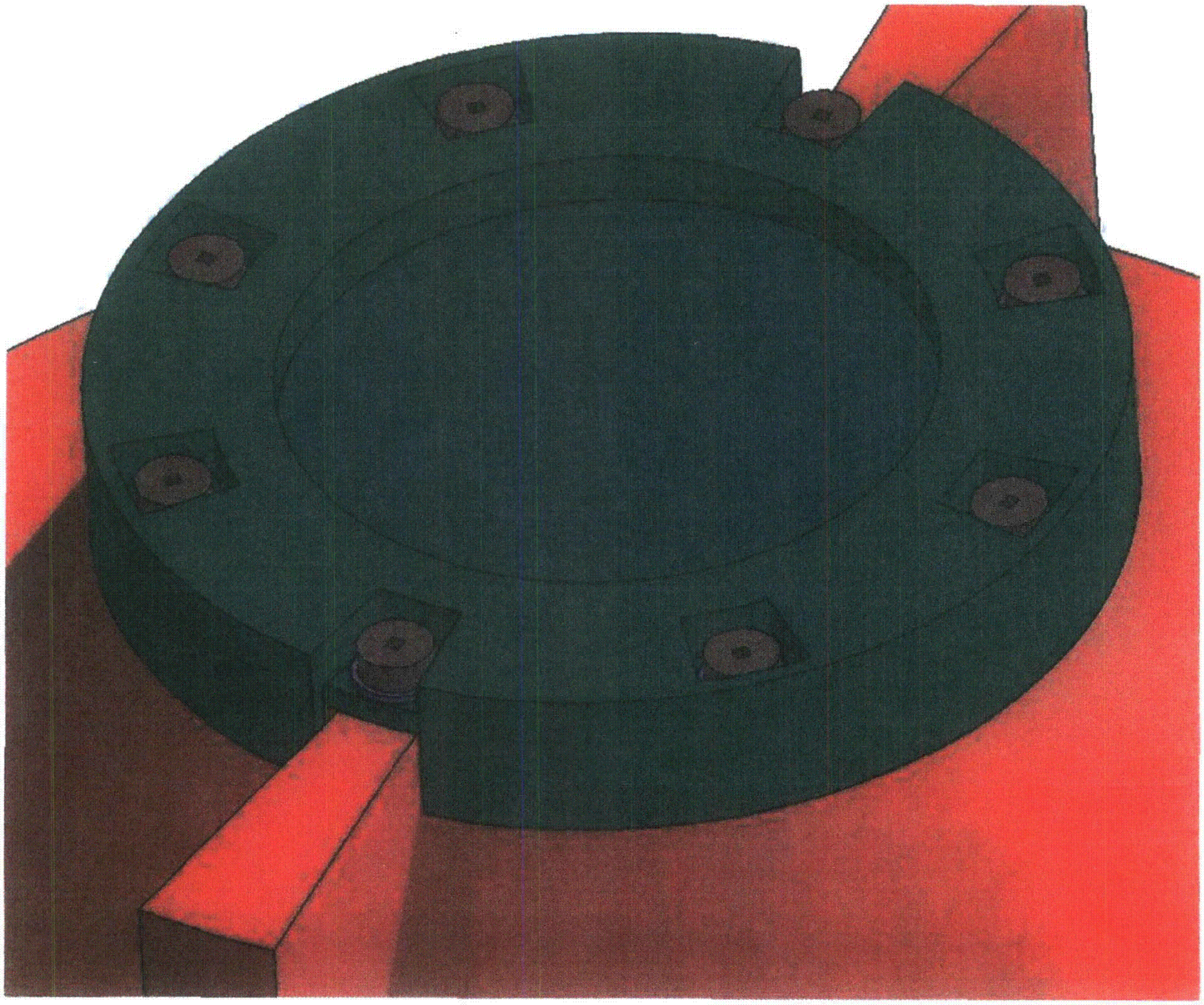

Figure 19: Zoomed View of Shield Liner with Bolt-Protecting Impact Plate

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Figure 20: Shield Liner (Typical) Lid with Bolts and Washers; Unmeshed

Figure 21: Shield Liner (Typical) Lid with Bolts and Washers; Meshed

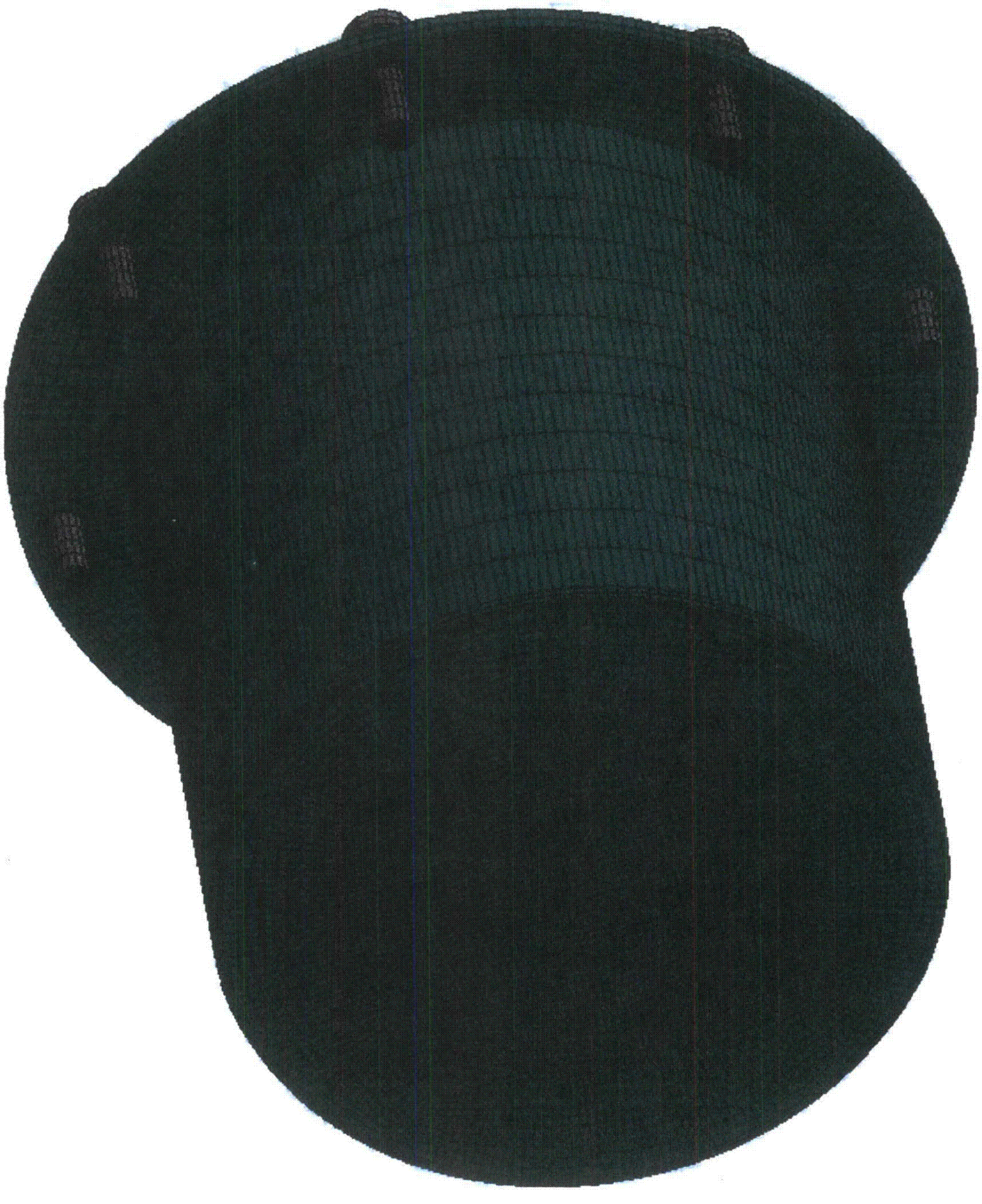

Figure 21: Bottom View of Shield Liner (Typical) Lid with Bolts and Washers; Meshed

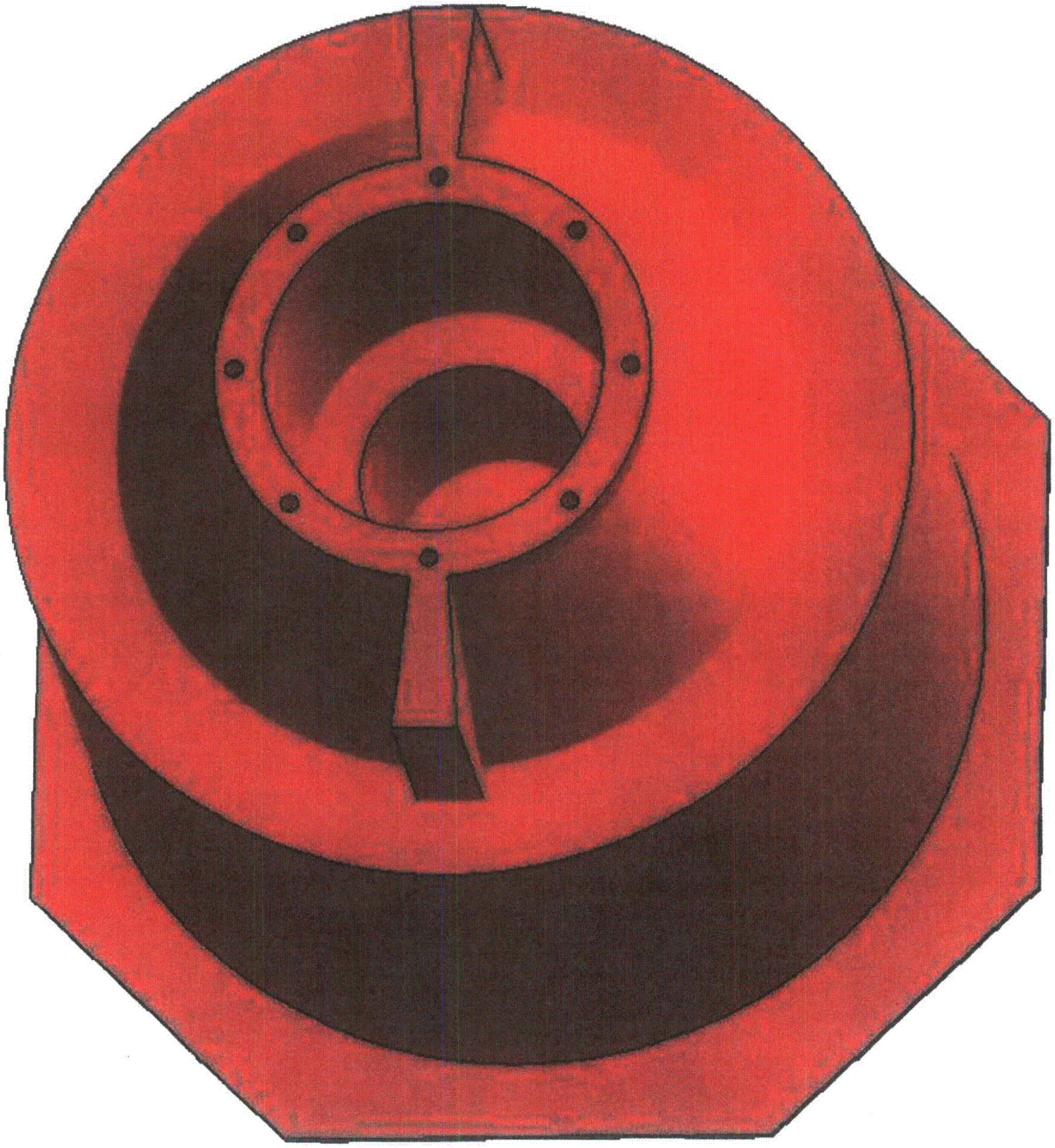

Figure 22: Shield Liner (Typical) Outer Shell Only; Unmeshed

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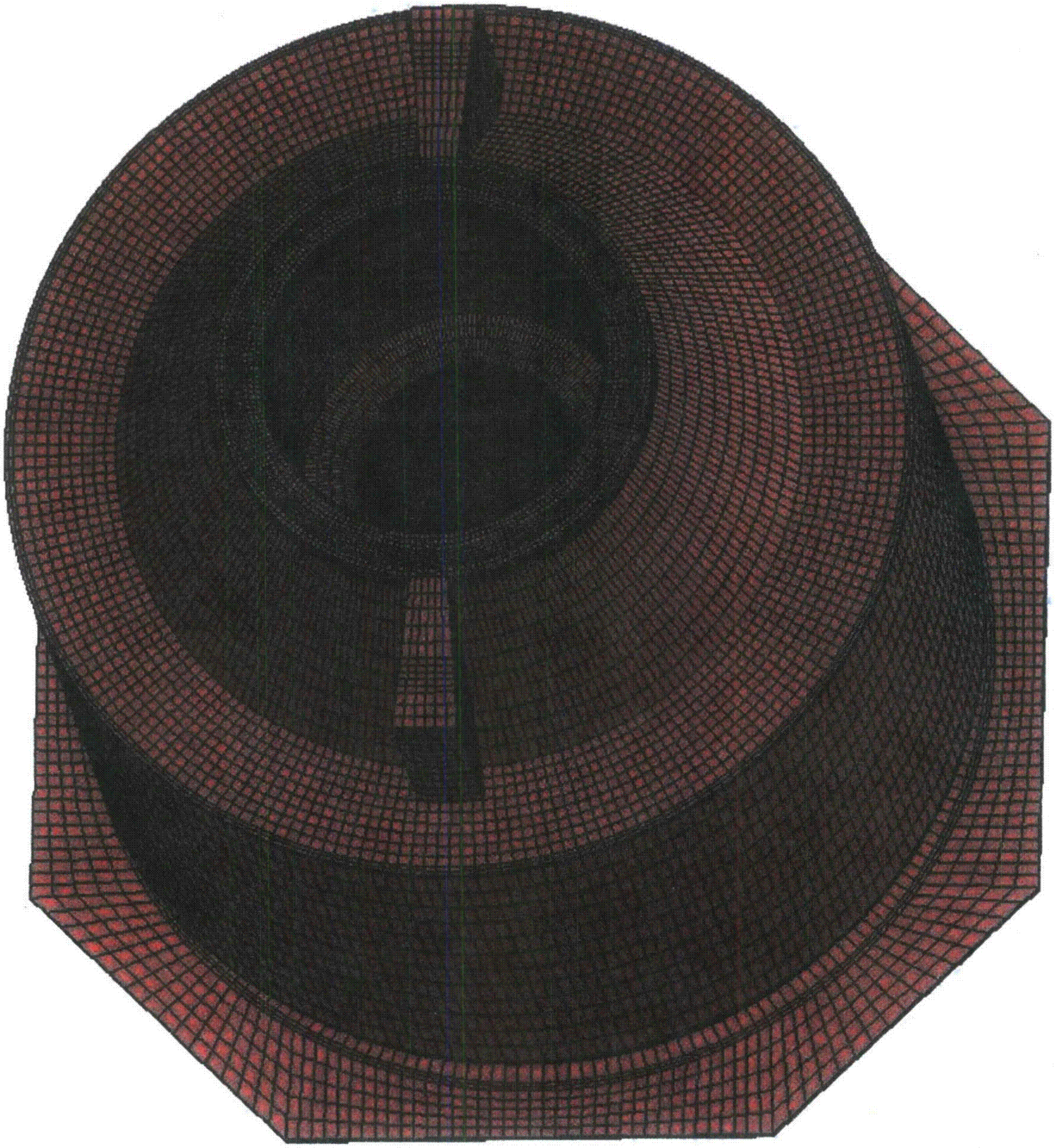

Figure 23: Shield Liner (Typical) Outer Shell Only; Meshed

RING ASSEMBLY SHORING

The ring assembly shoring was created from dwg BU650B-RA and is shown in Figures 24 through 26. Because of the addition of the bolt-protecting impact plate on top of the shield liner, the overall height of the shoring was reduced to 19.6875" to allow for a 0.25" clearance between the top of the shoring and the BU650B closure lid bottom when the shoring is resting on top of the shield liner. All coincident nodes of the ring assembly shoring components were allowed to merge. The ring assembly shoring as modeled weighs 192.31 lbs and is model part #33.

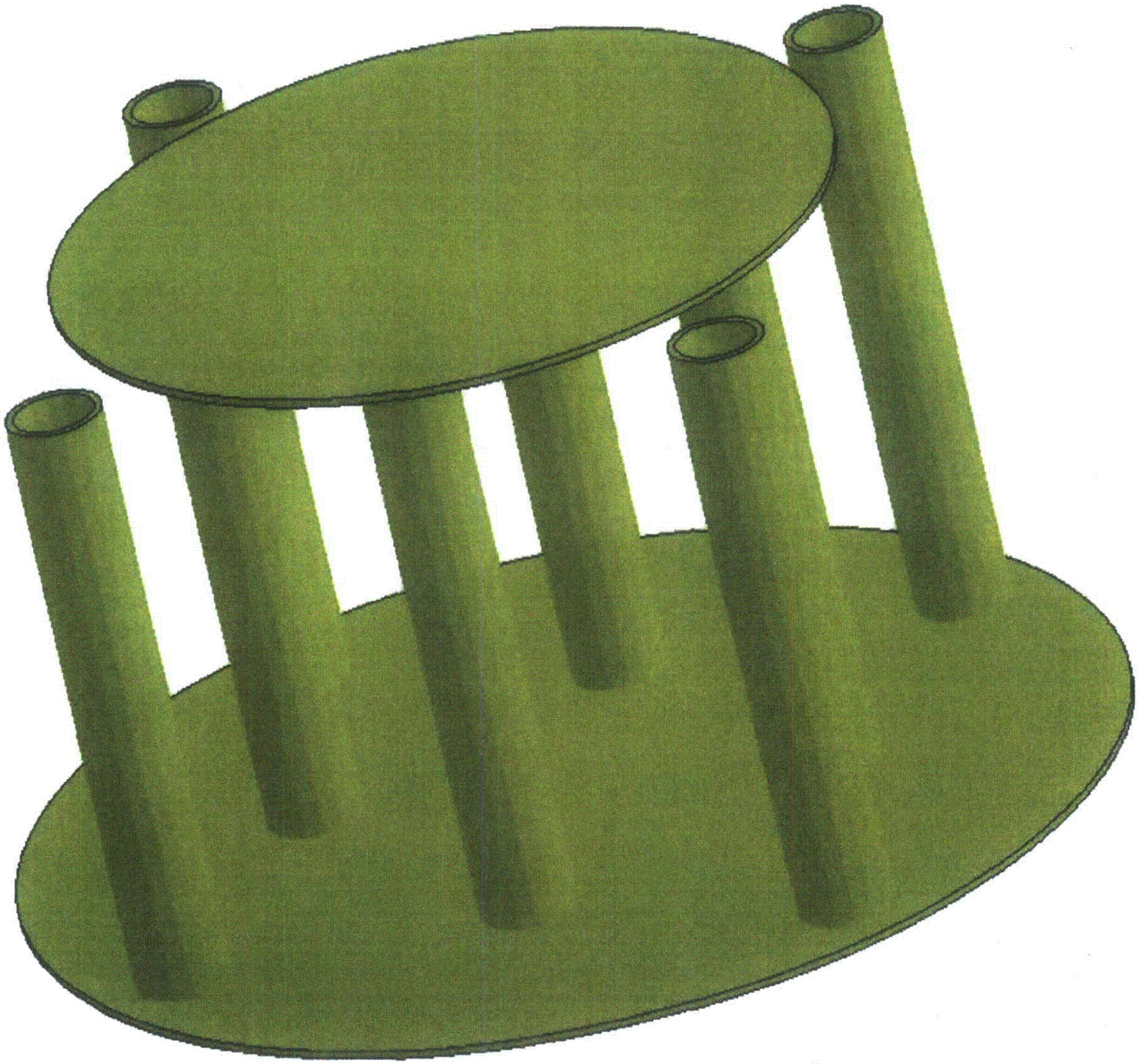

Figure 24: Ring Assembly Shoring; Unmeshed

Figure 25: Ring Assembly Shoring; Meshed

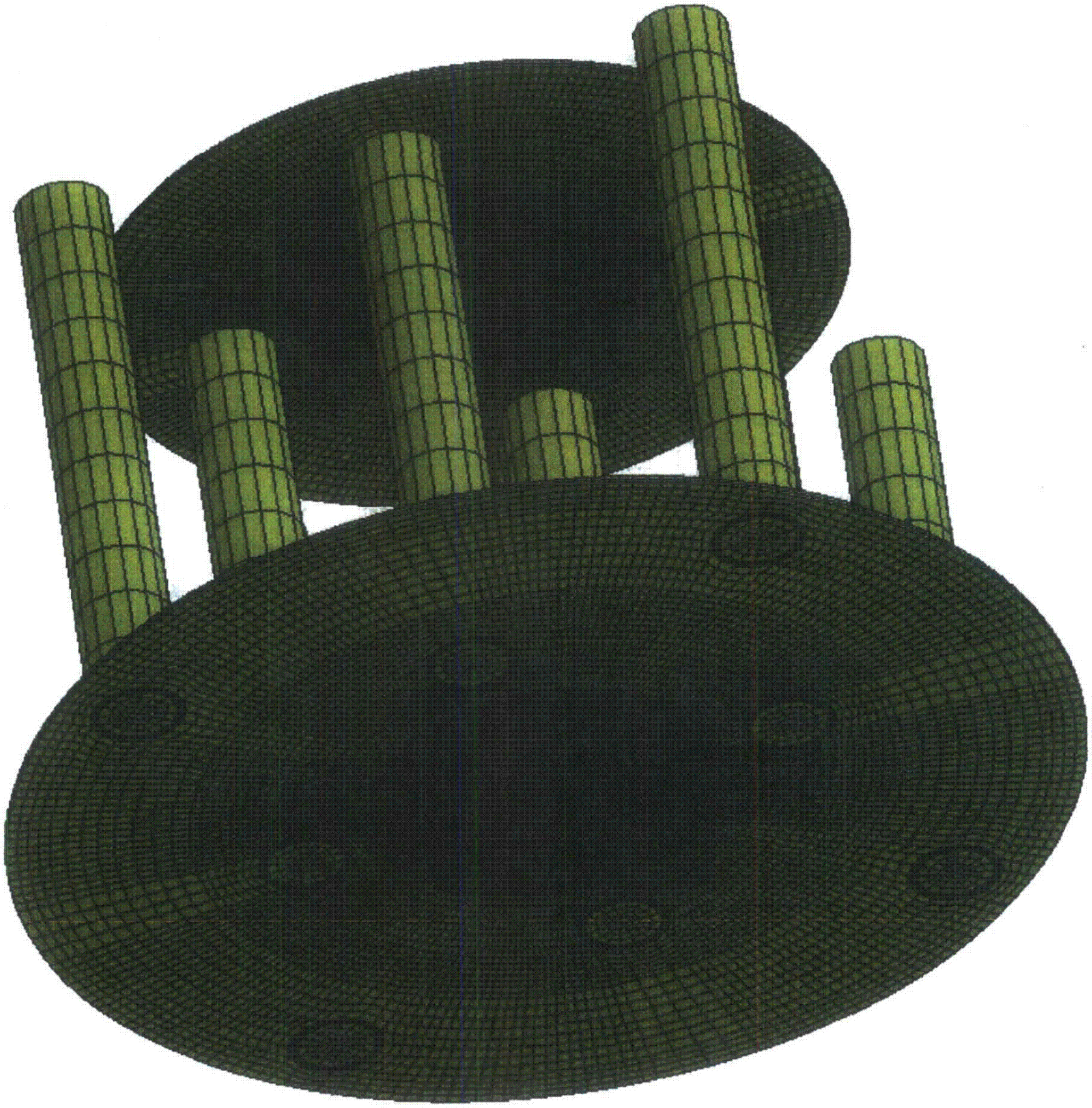

Figure 26: Ring Assembly Shoring Bottom View; Meshed

DEFINING THE MOST DAMAGING FREE DROP IMPACT ORIENTATION

The most damaging 30 ft free drop impact simulation was identified by analyzing the maximum plastic strains of the BU650B outer body bolts and the inner shield liner bolts from the following impacts: top, side and every 5 degree rotation in between. The plastic strain results for each component except the outer impact limiter shell (high plastic strains as expected) at every impact orientation are listed in Table 2 and 3. Both the outer bolt and inner core bolt parts for the body closure bolts (Parts 10 and 119) and shield liner closure bolts (Parts 106 and 121) are identified in bold. The maximum plastic strain values identifying the worst case drop orientation are identified in red.

Hourglass modes are nonphysical, zero-energy modes of deformation that produce zero strains and no stress and cause elements to lock up. LS-DYNA has various algorithms for inhibiting hourglass modes and the one used for this modeling task is hourglass control type 5, the Flanagan-Belytschko stiffness form with exact volume integration for solid elements (EQ.5). The stiffness forms can stiffen the response especially if deformations are large and therefore should be used with care. However, for lower velocities as is the case for this analysis task, it is preferred to use stiffness rather than viscous hourglass control. The default hourglass coefficient for EQ.5 is 0.1 and was used for all run data identified in Table 1 and 2. However, it is recommended by many LS-DYNA users from experience to use a coefficient *between 0.03 and 0.05. For comparison purposes to obtain the worst case orientation, all impact* orientation sets of run data used the default of 0.1. Then, the plastic strain data with an hourglass coefficient (EQ.5) of 0.05 was obtained for the established worst case to compare to the default values.

Part #	Part Identification	Top	5 deg	10 deg	15 deg	20 deg	25 deg	30 deg	35 deg	40 deg	45 deg
1	Cask Body Outer Btm Plate	0.89	4.71	5.03	2.33	2.12	1.88	1.69	1.09	3.81	4.41
2	Cask Body Inside Btm Plate	0.49	0.32	0.60	0.82	0.93	1.10	1.14	1.24	1.26	1.16
3	Cask Body Btm Plate Lip	0.37	0.18	0.33	0.43	0.55	0.59	0.61	0.68	0.71	0.51
4	Cask Body Outer Cylinder	0.63	1.46	0.59	0.63	0.70	0.86	1.02	1.13	1.07	1.05
5	Cask Body Inside Cylinder	0.10	1.00	1.22	1.37	1.46	1.55	1.55	1.80	1.99	2.37
6	Cask Body Top Closure Ring	2.88	3.81	8.00	14.47	23.40	30.14	31.08	36.04	33.16	50.63
8	Cask Body Welded Nut	0.86	13.48	13.24	17.79	13.04	19.10	18.82	17.37	24.20	3.82
10	**Cask Outer Bolt**	7.74	10.00	14.56	16.53	13.17	11.15	9.96	9.38	9.07	6.71
12	Cask Body Washers	0.38	0.41	1.08	0.96	0.88	0.59	0.49	0.40	0.41	0.40
25	Cask Lid Bolting Plate	4.34	4.42	4.62	4.11	5.68	5.39	5.79	5.80	5.77	6.21
26	Cask Lid Mid Plate	1.76	2.91	2.15	1.28	1.04	0.95	0.87	0.83	0.80	0.70
27	Cask Lid Out Cyl	*9.03*	*12.66*	*12.25*	*10.83*	*9.86*	*8.19*	*8.01*	*8.32*	*8.17*	*8.47*
28	Cask Lid Ins Cyl	8.39	7.59	5.83	4.24	2.29	1.53	1.47	1.31	1.32	1.16
29	Cask Lid Top Plate	9.96	10.21	13.20	9.94	9.07	7.36	7.42	10.78	11.26	12.43
30	Cask Lid Out Cyl w/Weld	47.28	77.70	85.21	75.64	63.02	53.69	54.32	58.45	73.03	52.54
31	Cask Lid Ins Plate	27.10	27.00	22.54	16.11	11.75	10.39	9.29	8.96	8.82	9.22
32	Cask Lid Ins Cyl w/Weld	30.49	30.06	26.09	21.06	15.42	12.00	8.94	11.17	10.40	12.49
33	Inside Shoring	54.40	53.44	35.46	26.87	33.90	28.22	25.69	25.53	24.90	27.28
57	Impact Limiter Inner Angle	19.29	30.99	30.96	26.58	28.78	26.69	26.60	27.58	28.28	29.27
70	Lifting Ring; Impact Limiter	6.74	16.87	20.11	11.13	11.65	10.93	10.13	14.87	15.66	19.49
72	Bolting Lug; Impact Limiter	27.28	24.71	38.18	63.98	62.37	62.39	59.62	58.42	60.56	64.56
73	Pins; Cask Body / Impact Limiter	9.42	10.19	17.28	37.28	90.67	115.10	138.27	132.80	126.50	56.90
100	Shield Liner Lid Closure Shell	52.03	53.03	41.10	44.12	38.03	37.93	34.69	30.63	28.54	21.44
104	Shield Liner Lid Lead	2.21	2.33	1.46	0.90	0.64	0.80	0.81	1.09	1.23	1.65
105	Shield Liner Content	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	**Shield Liner Bolts**	7.20	3.71	2.32	1.91	1.25	2.67	3.80	6.34	9.19	4.80
109	Shield Liner Washers	1.10	0.55	0.11	0.07	0.00	0.92	0.35	0.81	1.32	1.86
112	4x4 Mounting Bracket; Cask Body	2.42	3.50	3.28	5.61	5.71	5.90	6.15	6.21	5.99	5.50
113	Mounting Bracket Lug; Cask Body	20.46	28.21	37.82	51.24	50.24	47.64	56.64	56.41	57.92	62.68
114	Mounting Brackets Welds	3.10	6.01	10.00	5.92	6.10	5.71	6.00	7.87	8.41	8.87
119	**Cask Body Bolts Core**	7.63	8.89	13.48	16.13	12.89	10.85	9.54	8.96	8.68	6.16
121	**Shield Liner Bolts Core**	2.04	1.95	1.15	0.80	0.19	0.52	0.92	1.37	2.22	2.76
124	Impact Plate on Shield Liner	28.88	115.56	48.34	36.34	50.49	43.57	39.52	37.67	43.90	35.12

Table 1: Component Maximum Plastic Strains (%); Top through the 45 degree Impacts

Part #	*Part Identification*	*50 deg*	*55 deg*	*60 deg*	*65 deg*	*70 deg*	*75 deg*	*80 deg*	*85 deg*	*Side*
1	Cask Body Outer Btm Plate	0.62	0.44	2.69	0.53	5.84	6.44	1.90	1.66	5.65
2	Cask Body Inside Btm Plate	1.36	1.30	2.07	2.86	5.29	5.30	5.77	4.42	8.61
3	Cask Body Btm Plate Lip	0.75	0.72	1.65	2.43	3.16	3.29	3.65	2.48	5.29
4	Cask Body Outer Cylinder	0.96	0.85	1.21	0.95	3.11	3.06	5.86	5.22	2.15
5	Cask Body Inside Cylinder	1.99	2.00	1.94	1.50	2.83	2.33	2.68	2.80	3.65
6	Cask Body Top Closure Ring	25.14	8.96	1.92	1.15	3.04	4.21	4.41	5.21	5.72
8	Cask Body Welded Nut	16.19	29.15	13.60	12.88	17.27	15.42	13.71	18.53	11.47
10	**Cask Outer Bolt**	7.37	6.29	4.19	4.09	4.55	6.24	6.80	9.23	8.73
12	Cask Body Washers	0.35	0.30	0.16	0.10	0.37	0.98	0.41	1.36	0.44
25	Cask Lid Bolting Plate	4.81	2.76	2.66	3.39	3.46	3.25	2.09	2.97	3.91
26	Cask Lid Mid Plate	0.67	0.67	0.52	0.43	0.36	0.24	0.25	0.33	0.26
27	Cask Lid Out Cyl	7.80	7.95	6.75	2.81	1.63	2.44	1.25	1.48	0.99
28	Cask Lid Ins Cyl	0.83	0.78	0.41	0.28	0.24	0.23	0.29	0.34	0.44
29	Cask Lid Top Plate	13.83	14.46	16.86	16.24	17.23	17.94	15.96	16.45	13.33
30	Cask Lid Out Cyl w/Weld	51.68	52.87	90.66	31.16	13.77	15.79	3.85	6.39	3.14
31	Cask Lid Ins Plate	6.73	6.54	4.53	3.52	6.58	2.34	2.35	3.08	3.55
32	Cask Lid Ins Cyl w/Weld	9.63	9.19	4.91	4.00	3.53	2.93	3.18	4.09	3.16
33	Inside Shoring	25.70	24.57	22.65	20.36	16.73	13.78	13.77	12.18	10.88
57	Impact Limiter Inner Angle	24.59	25.06	31.32	27.69	41.85	26.09	46.03	34.83	19.57
70	Lifting Ring; Impact Limiter	20.32	21.56	27.47	26.95	27.47	29.23	26.65	27.65	27.70
72	Bolting Lug; Impact Limiter	61.45	62.80	61.53	24.53	32.00	24.55	21.08	25.95	14.49
73	Pins; Cask Body / Impact Limiter	101.34	55.86	34.61	10.76	17.48	10.69	10.89	12.79	7.81
100	Shield Liner Lid Closure Shell	26.17	27.59	14.00	13.32	17.91	15.46	4.71	7.95	14.60
104	Shield Liner Lid Lead	1.13	1.06	0.51	0.27	0.40	0.18	0.14	0.41	0.73
105	Shield Liner Content	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
106	**Shield Liner Bolts**	3.86	3.52	0.73	0.68	2.53	1.19	1.23	1.77	2.41
109	Shield Liner Washers	1.34	1.42	0.45	0.00	0.22	0.00	0.00	0.00	0.00
112	4x4 Mounting Bracket; Cask Body	5.81	5.50	5.19	2.72	3.26	3.74	3.26	4.19	4.20
113	Mounting Bracket Lug; Cask Body	56.06	49.76	47.75	21.40	15.91	23.13	15.34	23.19	14.26
114	Mounting Brackets Welds	10.46	11.28	20.37	18.87	23.10	27.14	21.44	24.45	23.62
119	**Cask Body Bolts Core**	6.96	5.93	4.15	4.03	4.30	5.75	5.97	7.60	8.19
121	**Shield Liner Bolts Core**	2.02	1.82	0.26	0.12	1.86	0.77	0.83	1.17	1.69
124	Impact Plate on Shield Liner	27.83	28.76	47.16	26.27	19.41	18.51	18.12	27.69	4.66

Table 2: Component Maximum Plastic Strains (%); 50 degrees through the Side Impacts

Using only the BU650B main body closure bolts plastic strain results from Table 1 and Table 2, the worst case drop orientation is the BU650B rotated 15 degrees from the top (flat) impact as shown in Figure 27. Note the BU650B body closure bolts results shows a maximum singular value of plastic strain in all bolts of approximately 17% but is not an average. The results of various BU650B components in their resulting worst case impact orientation are shown in Figures 28 through 55. However, because of the sacrificial and energy absorbing purpose of the impact limiters, the impact limiter components are not shown because the plastic strain data for these individual components are not part of the packaging containment boundary and are not important. The impact limiter attachment ring, lugs and pins are shown to document the high probability that the impact limiters will remain attached to the BU650B body after the 30 ft drop impact even though failure of at least one attachment pin is expected from the results.

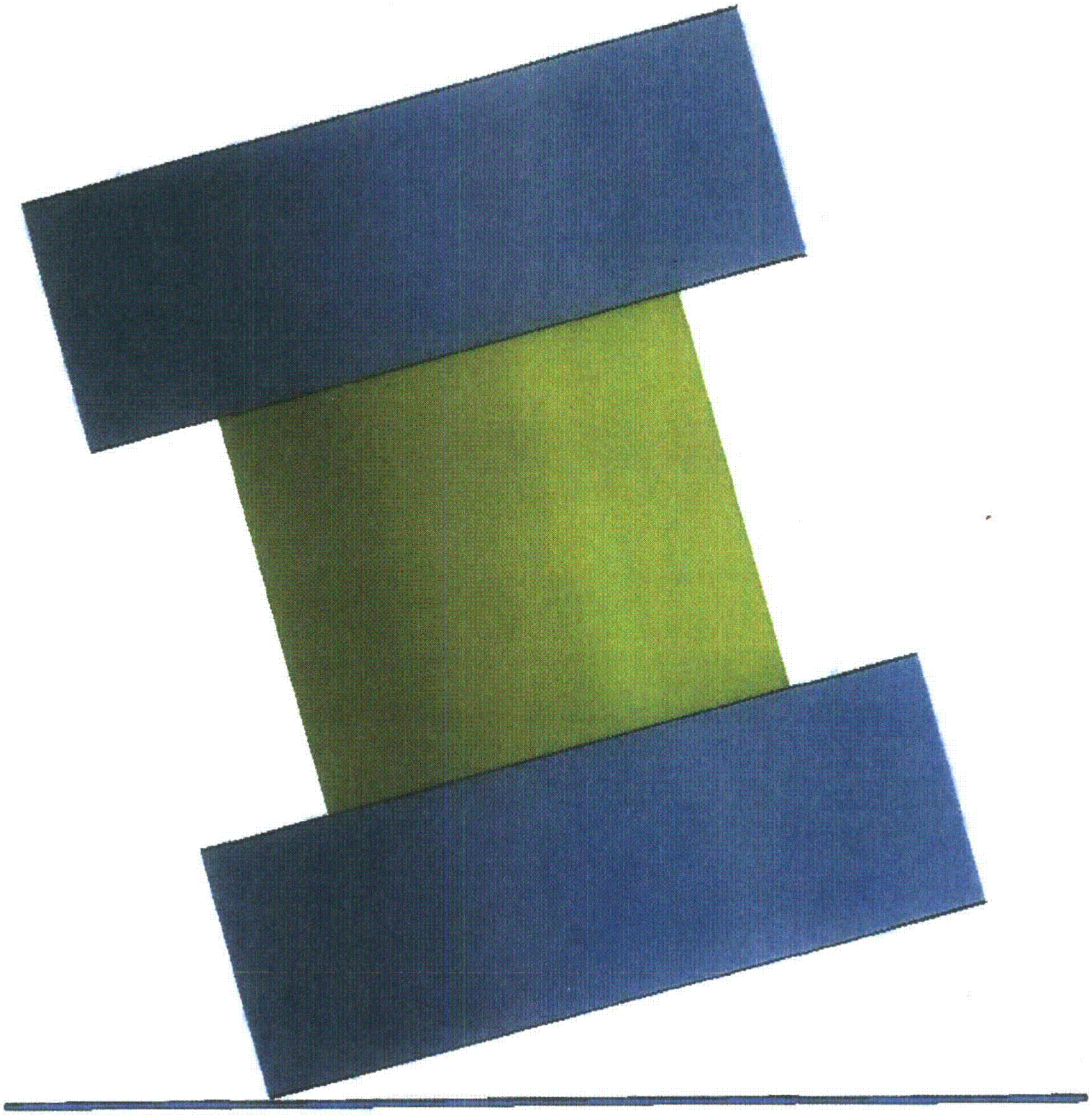

Figure 27: BU650B Worst Case Drop Orientation – 15 degree Rotation from Top (Flat) Impact

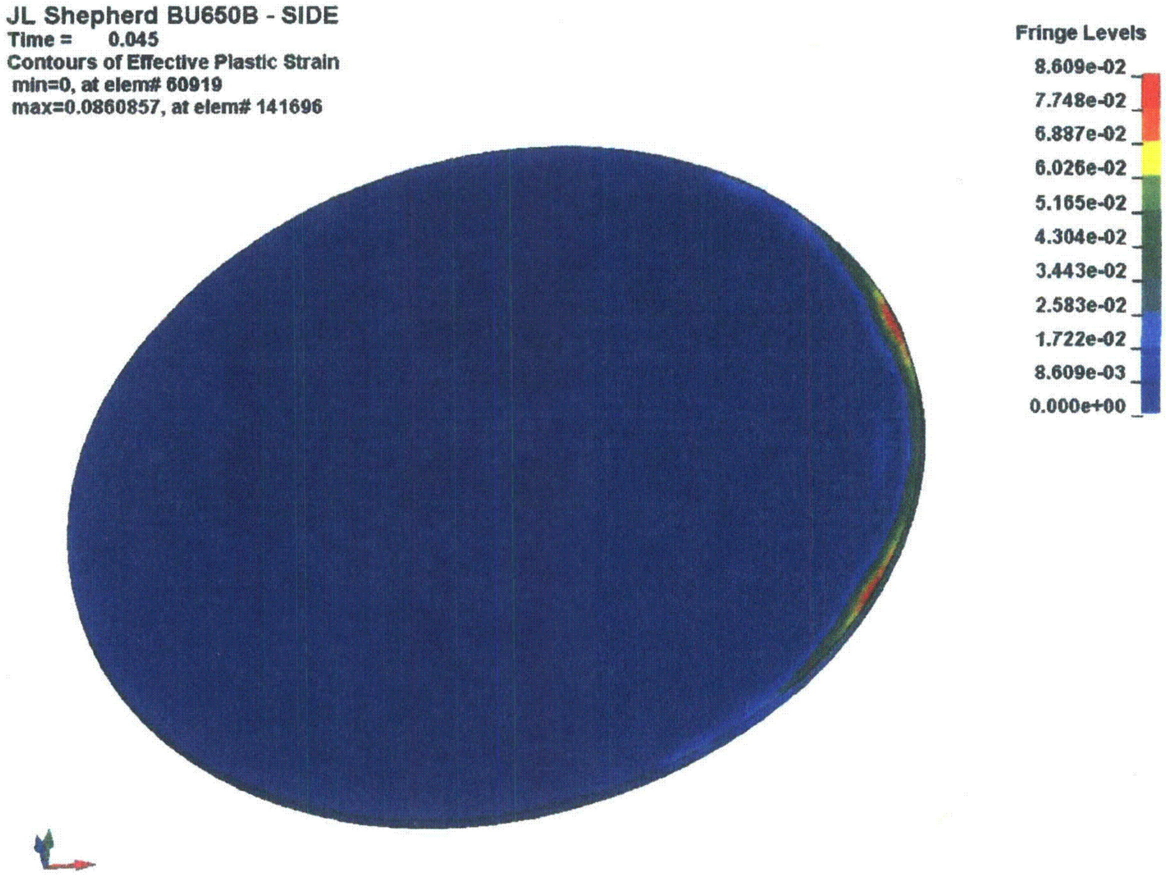

Figure 28: Part #2 – Cask Body Inside Bottom Plate; Max Plastic Strain 8.61% (Side Drop)

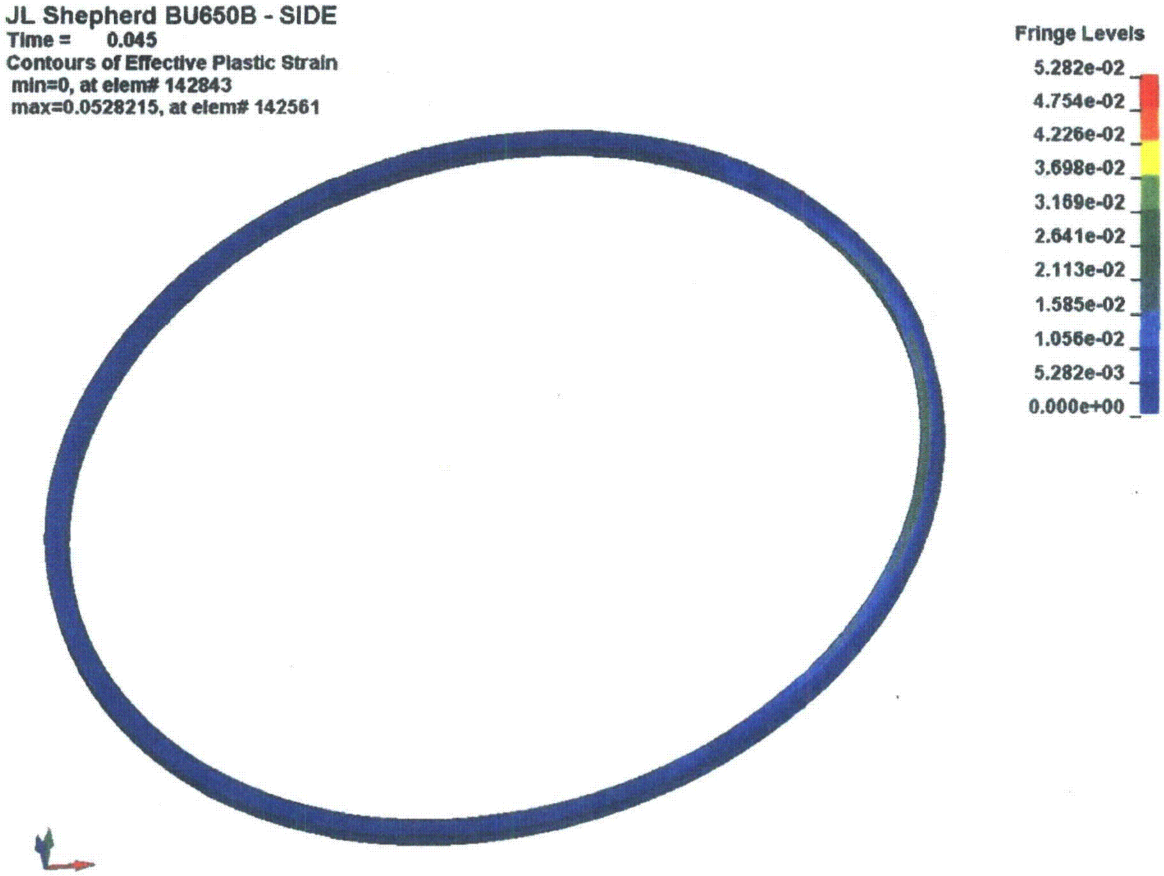

Figure 29: Part #3 – Cask Body Inside Bottom Plate Lip Extension with Weld; Max Plastic Strain 5.3% (Side Drop)

Figure 30: Part #4 – BU650B Outer Cylinder Body; Max Plastic Strain 5.9% (10 deg rotated from Side Drop)

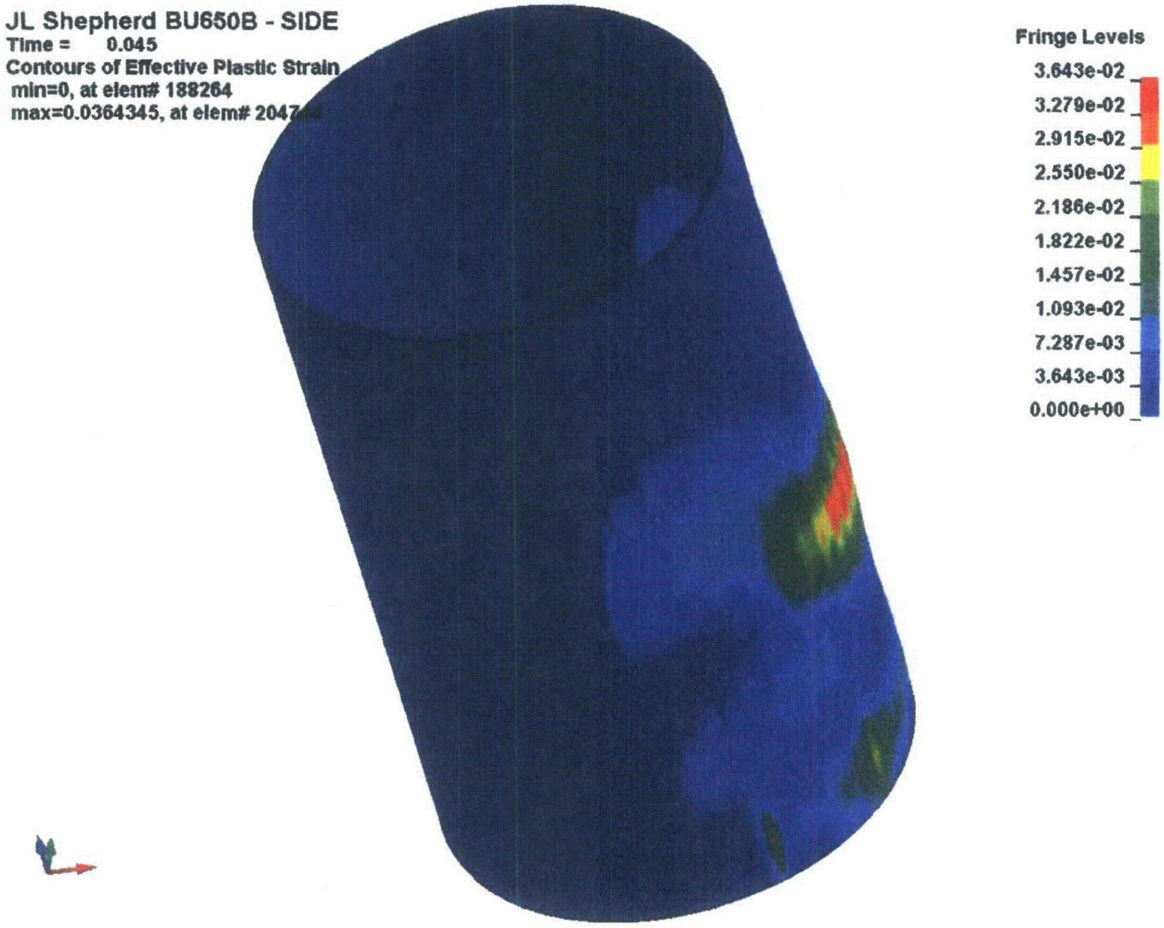

Figure 31: Part #5 – BU650B Body Inside Cylinder: Max Plastic Strain 3.65% (Side Drop)

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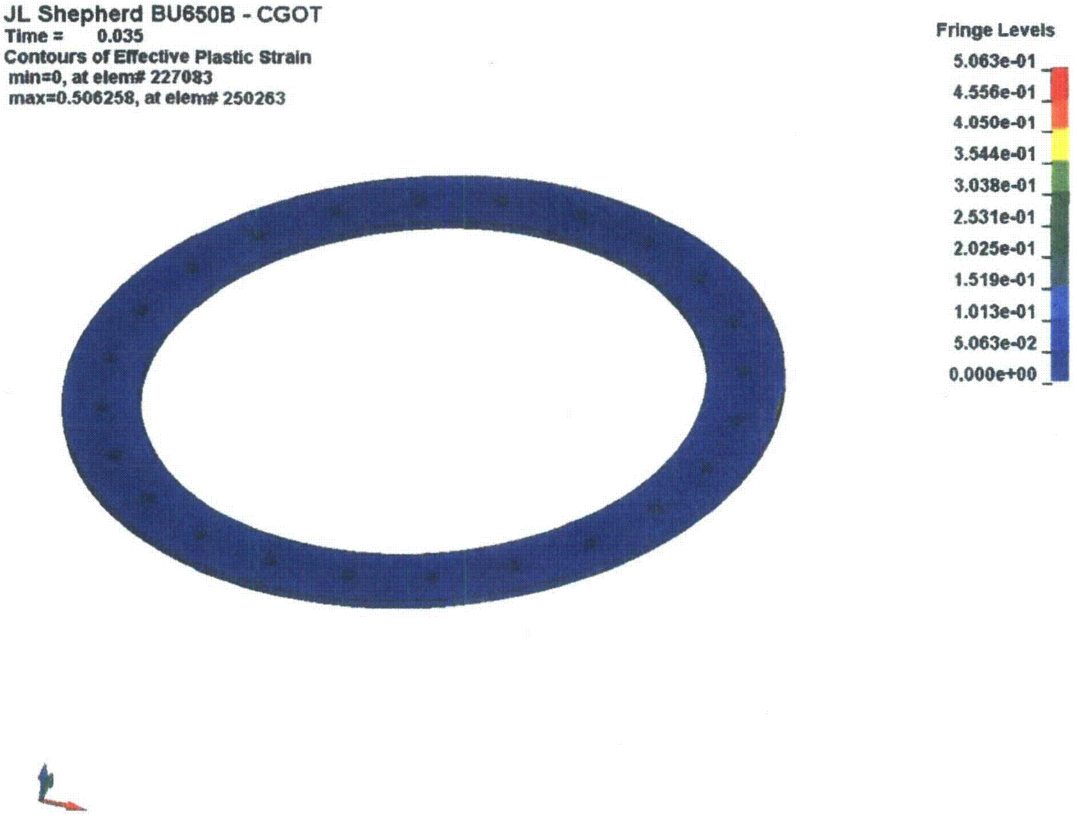

Figure 32: Part #6: BU650B Body Bolting Ring – Max Plastic Strain (Localized) 50.7% (45 deg rotated from Top Drop)

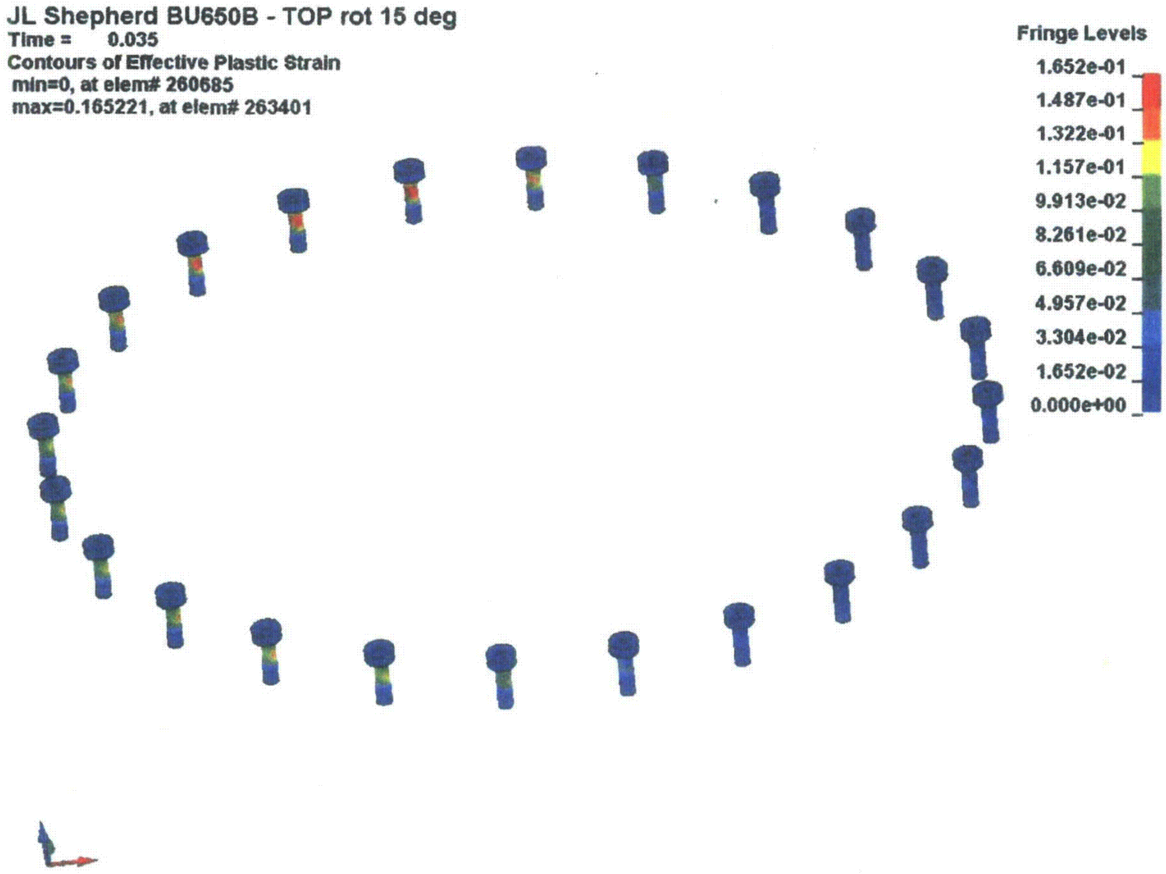

Figure 33: Part #10 – BU650B Body Closure Bolts (Outer Material, Not Core): Max Plastic Strain 16.6% (15 degree rotated from Top Impact)

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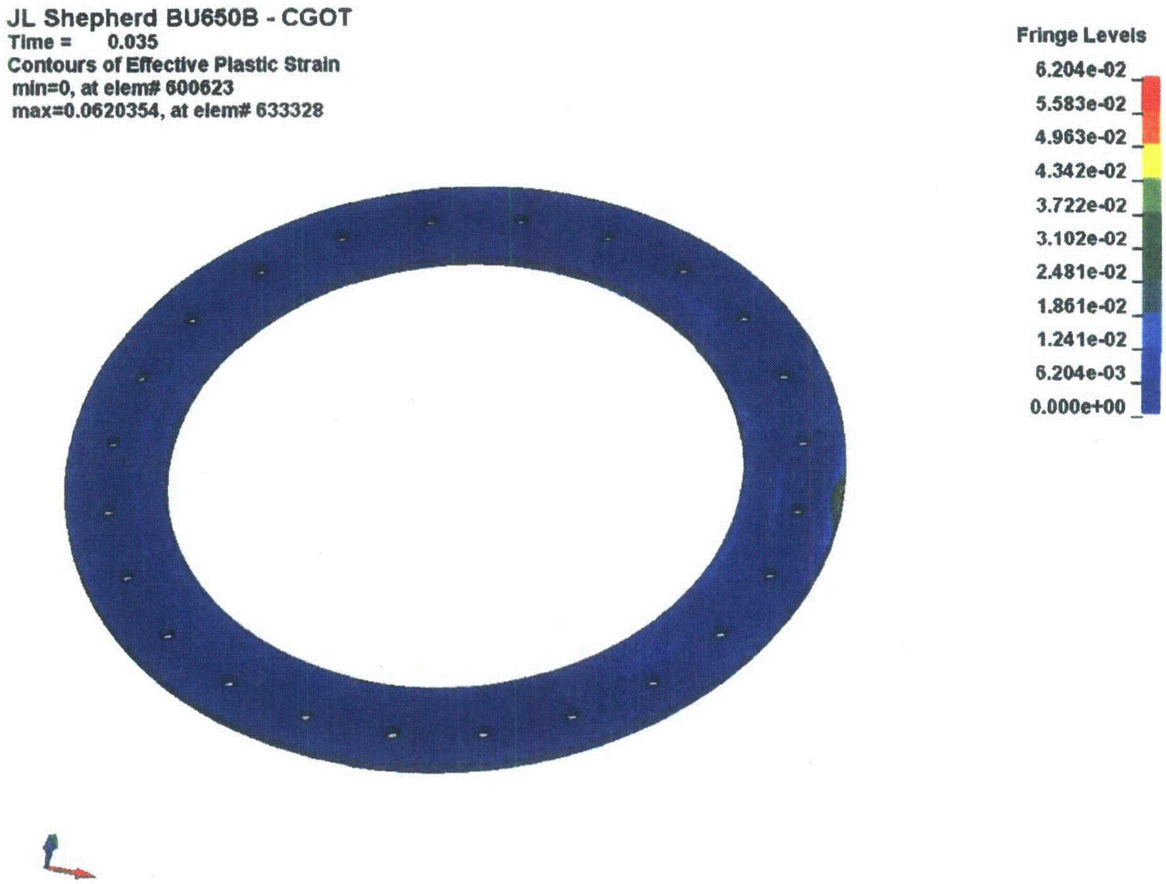

Figure 34: Part #25 – BU650 Lid Closure Plate: Max Plastic Strain 6.2% (Localized) (45 degree Top Impact)

Figure 35: Part #26 – BU650B Lid Middle Plate – Max Plastic Strain 2.9%
(Rotated 5 degrees from Top Impact)

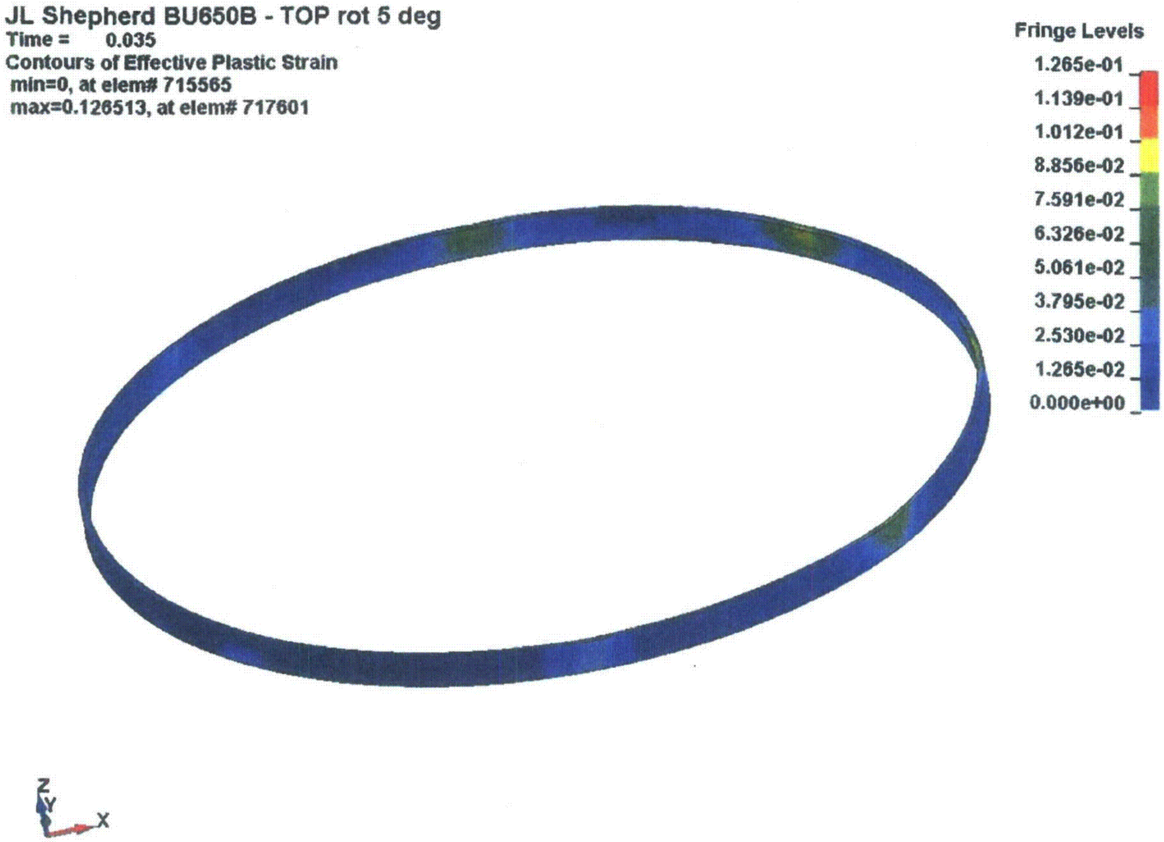

Figure 36: Part #27 – BU650B Lid Outer Cylinder: Max Plastic Strain 12.7% (Rotated 5 degrees from Top Impact)

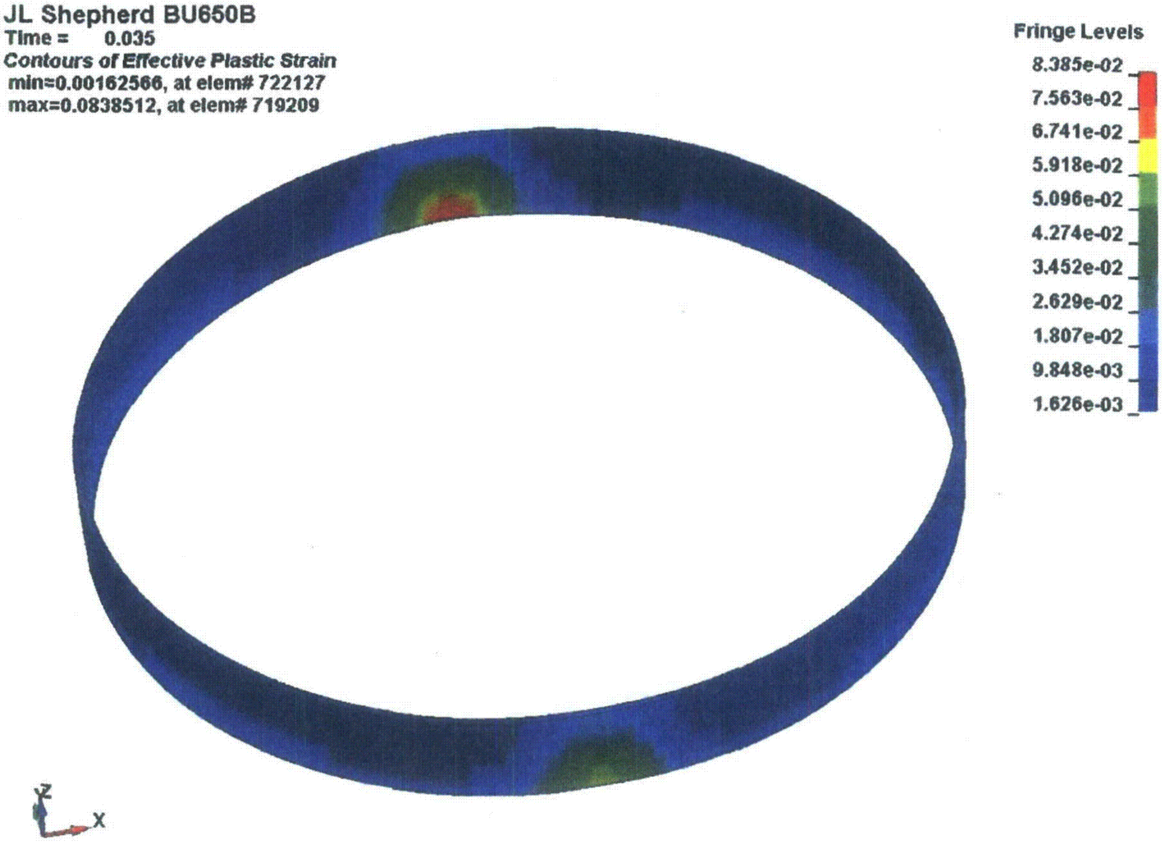

Figure 37: Part #28 – BU650B Cask Lid Inside Cylinder: Max Plastic Strain 8.4% (Localized) (Top Impact)

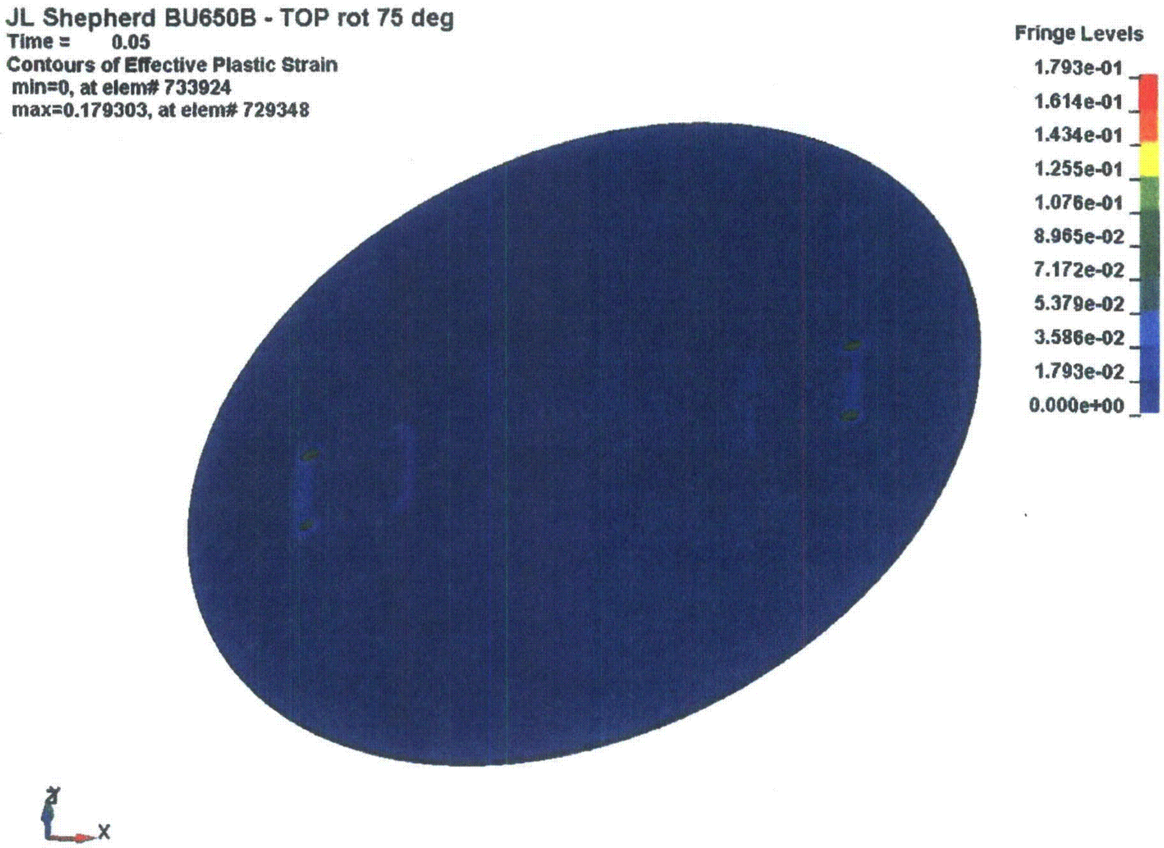

Figure 38: Part #29 – BU650B Lid Outside Plate – Max Plastic Strain 18% (Localized) (15 degree rotated from Side Impact)

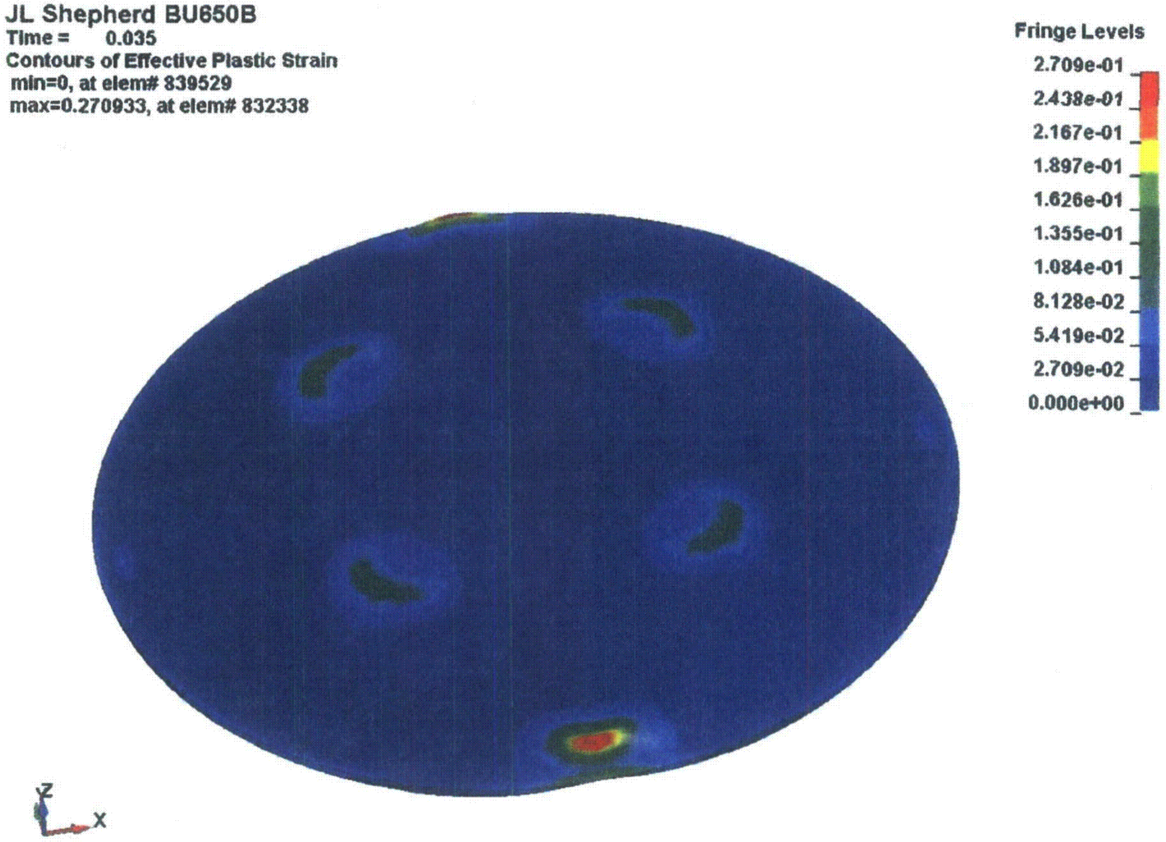

Figure 39: Part #31 – BU650B Lid Inside Plate: Max Plastic Strain 27.1% (Localized) (Top Impact)

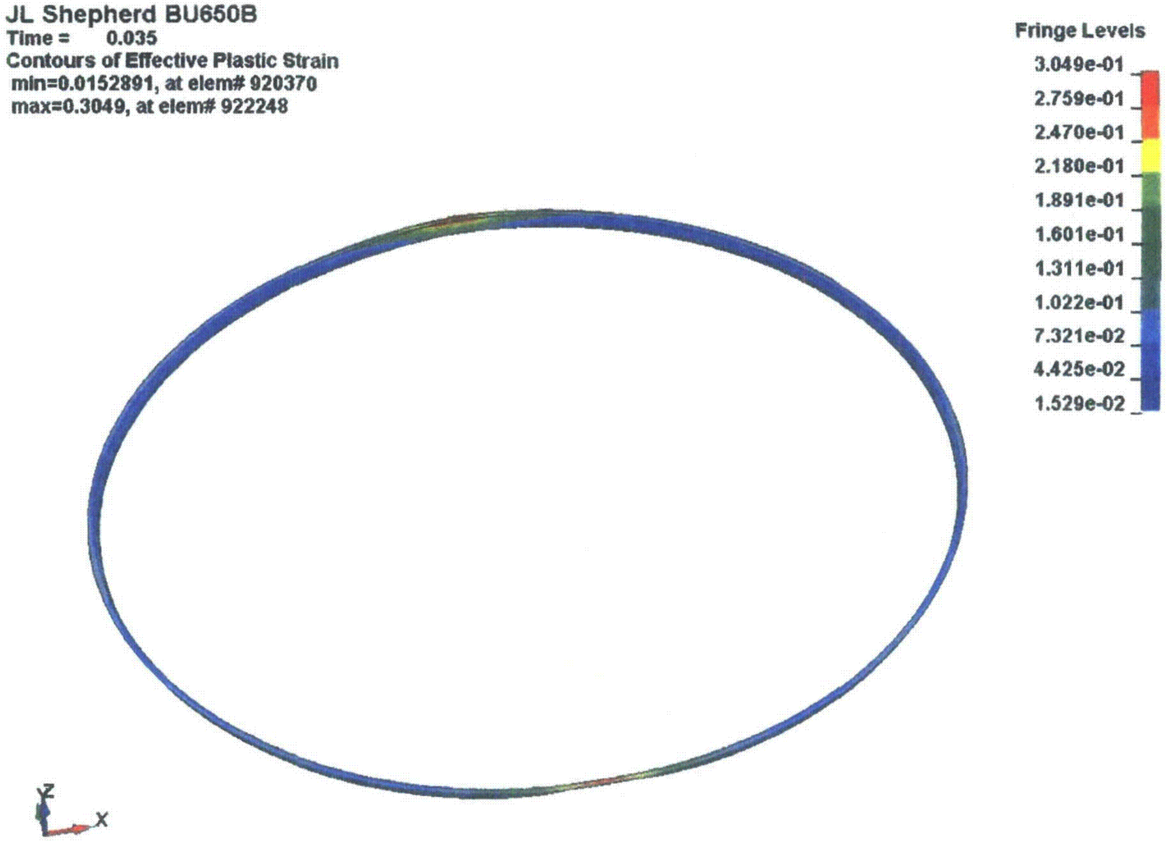

Figure 40: Part #32 – BU650B Lid Inside Cylinder with Weld: Max Plastic Strain 30.5% (Localized) (Top Impact)

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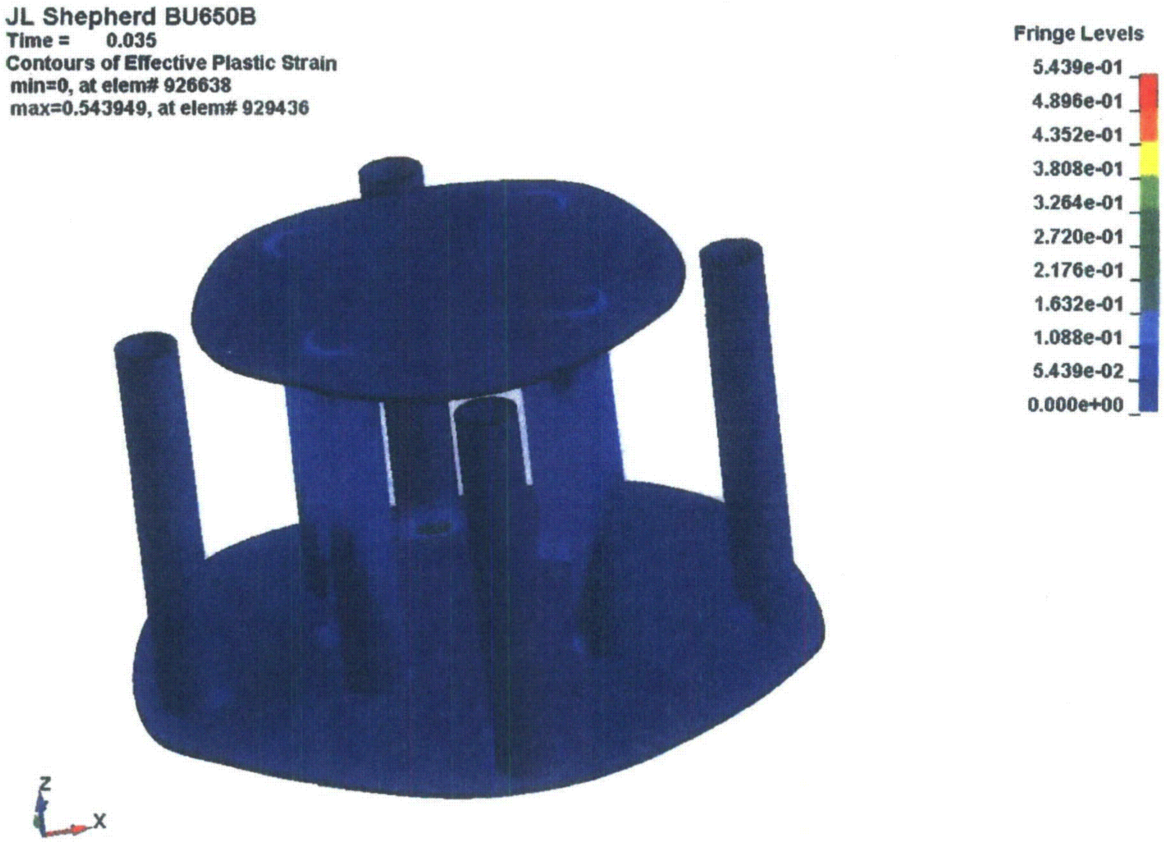

Figure 41: Part #33 – Shoring (Top View): Max Plastic Strain (Localized) 54.4% (Top Impact)

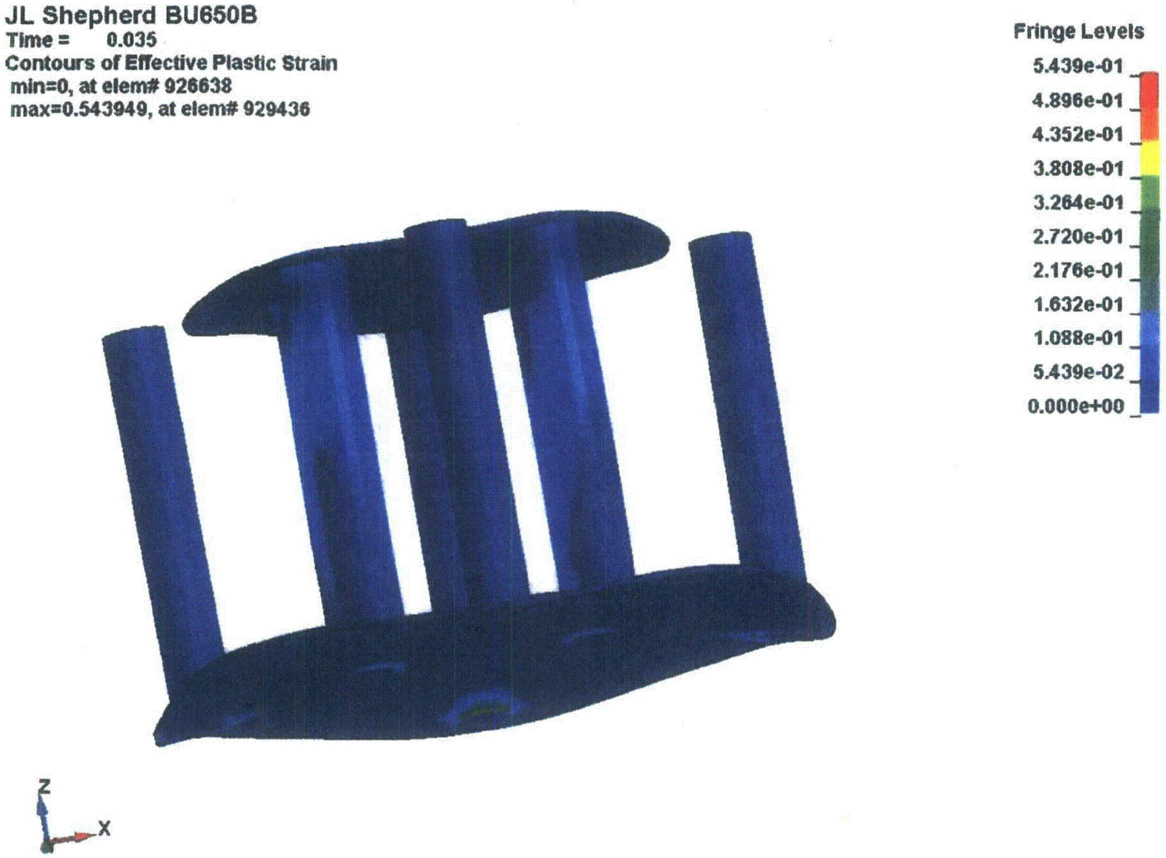

Figure 42: Part #33 – Shoring (Side View): Max Plastic Strain (Localized) 54.4% (Top Impact)

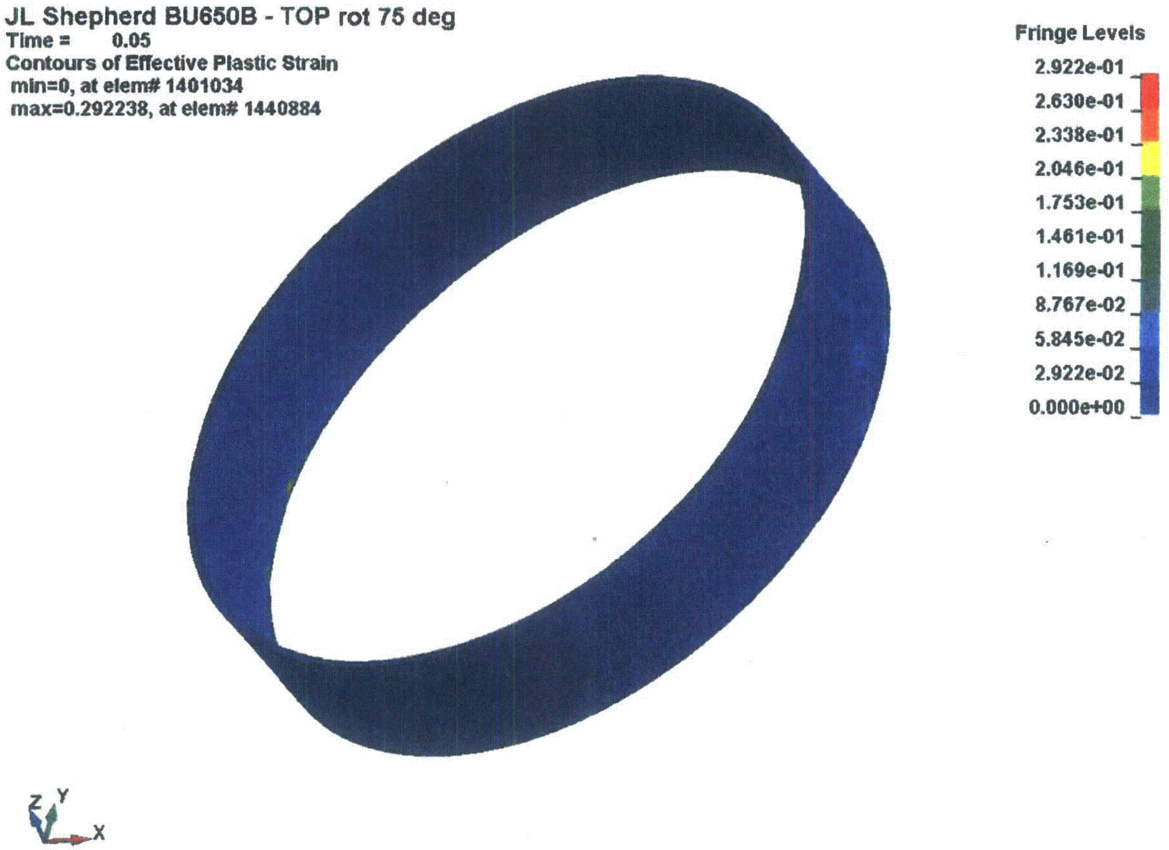

Figure 43: Part #70 – Lifting Ring Plate Inside of Impact Limiter: Max Plastic Strain (Localized) 29.3% (15 degree rotated from Side Impact)

Figure 44: Part #72 – Bolting Lugs on Impact Limiters (Top / Btm): Max Plastic Strain 64.6% (45 degree Impact on Lid)

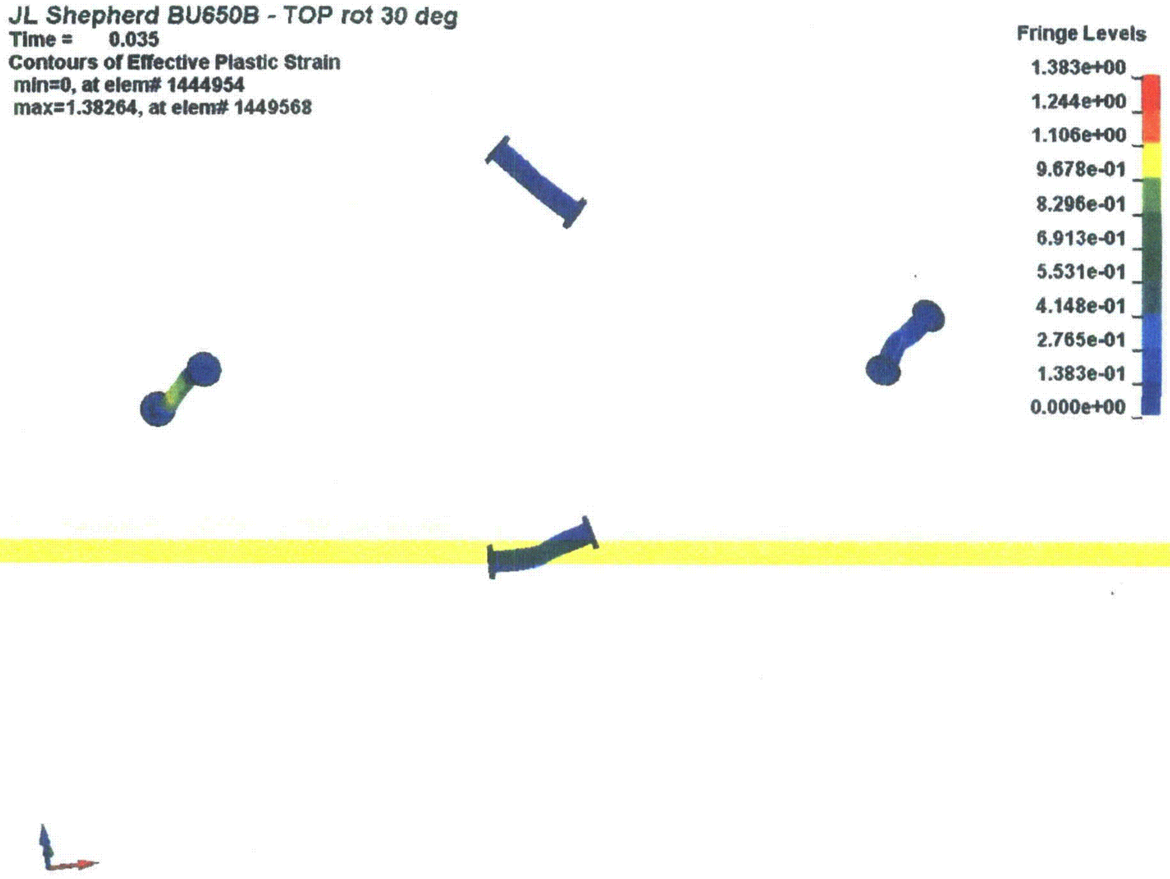

Figure 45: Part #73 – Body / Impact Limiter Attachment Pins: Excessive Plastic Strains Means Failure of at least one Pin (Rotated 30 degrees from Top Impact)

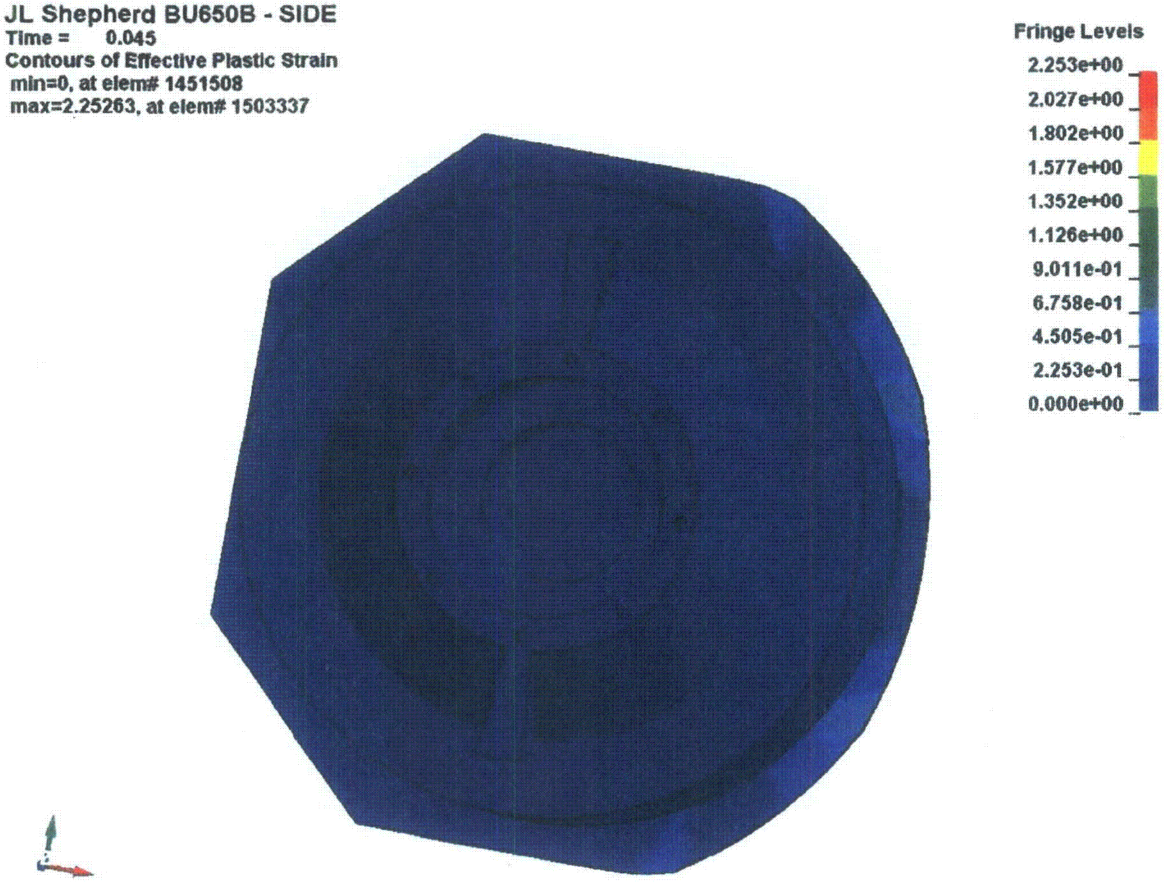

Figure 46: Part #76 – Shield Liner Outer Shell: Excessive Plastic Strains shows Major Deformation of the Lower Sheet Metal Shoring / Spacing Lip during Side Impact

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Figure 47: Part #100 – Shield Liner Lid Outer Shell: Max Plastic Strain (Localized) 53% (5 degree Rotated from Top Impact)

GENERAL DESIGN AND COMPUTATION SHEET

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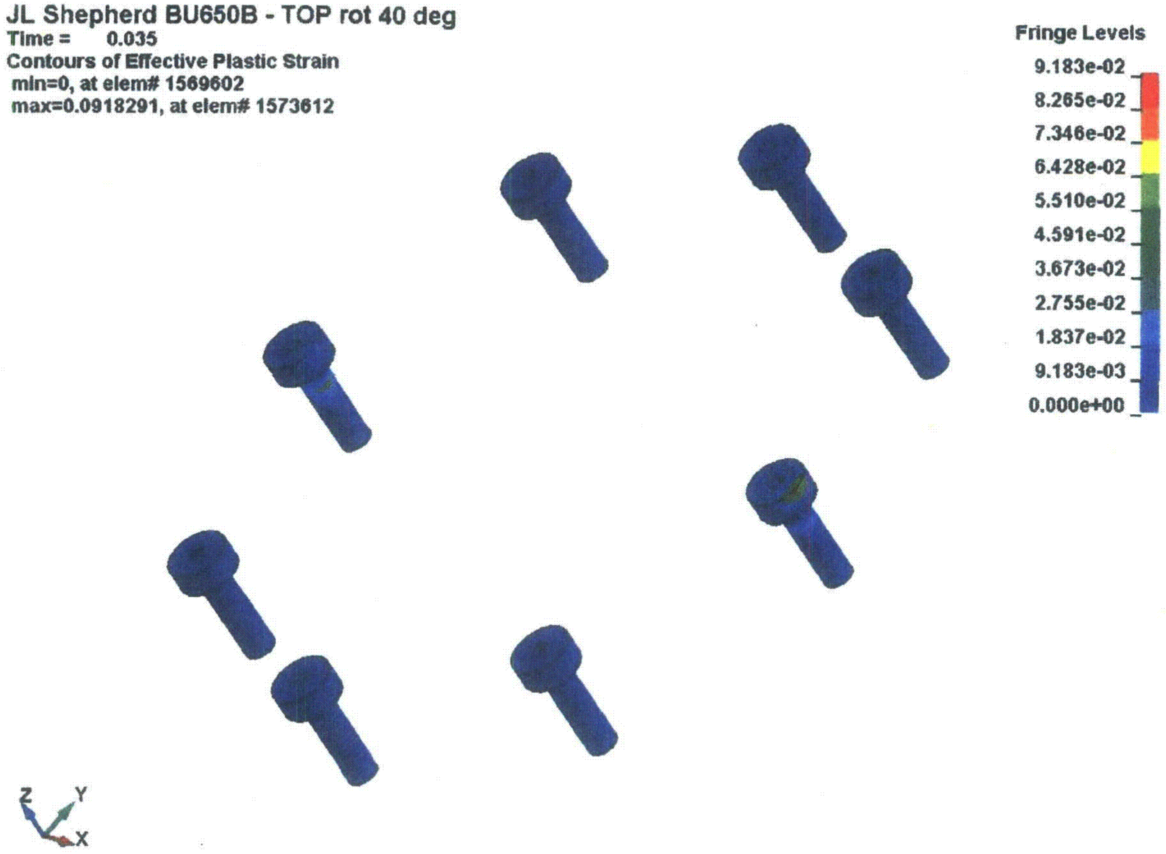

Figure 48: Part #106 – Shield Liner Closure Bolts (Outer Material, Not Core): Max Plastic Strain 9.2% (Rotated 40 degrees from Top Impact)

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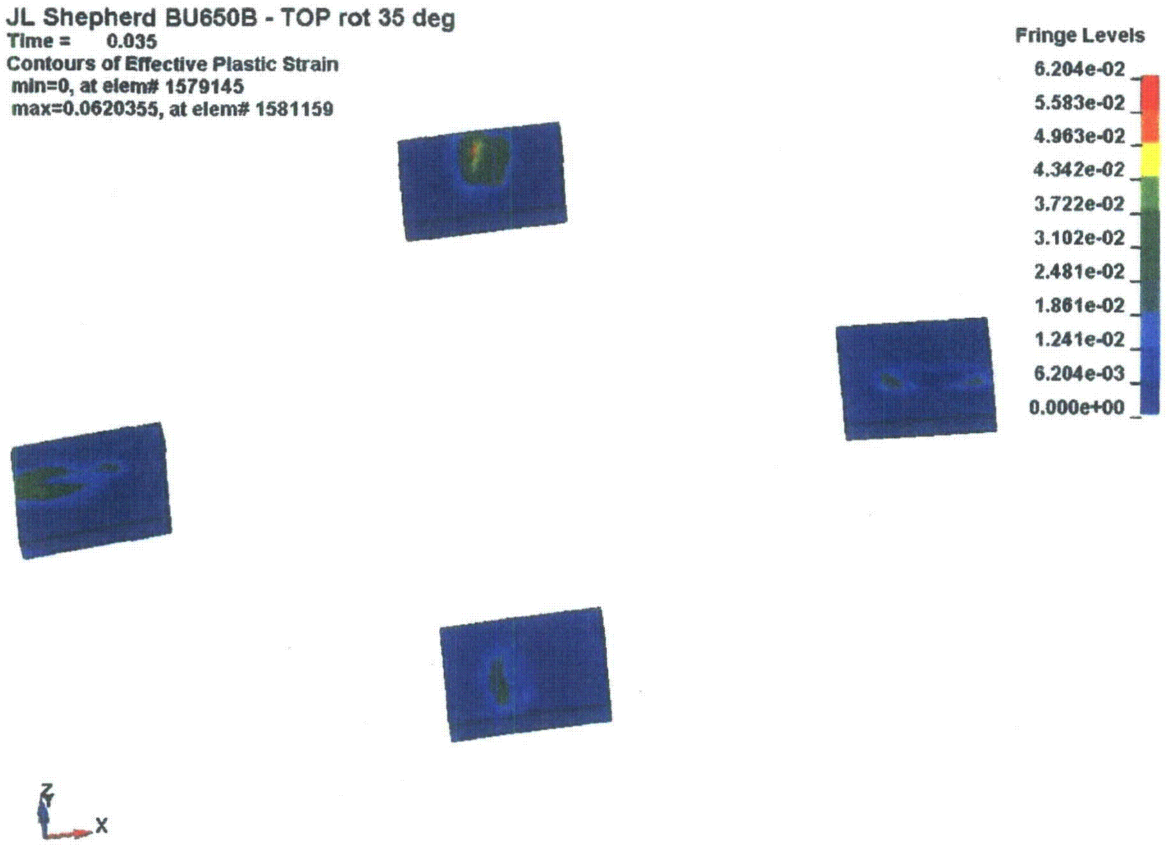

Figure 49: Part #112 – 4"x4" Mounting Brackets Welded to BU650B Body and Lid – Max Plastic Strain 6.2% (Rotated 35 degrees from Top Impact)

Figure 50: Part #113 – BU650B Body and Lid Mounting Bracket Lugs: Max Plastic Strain 62.7% (Some Tearout Failures); (45 degree Impact on Lid)

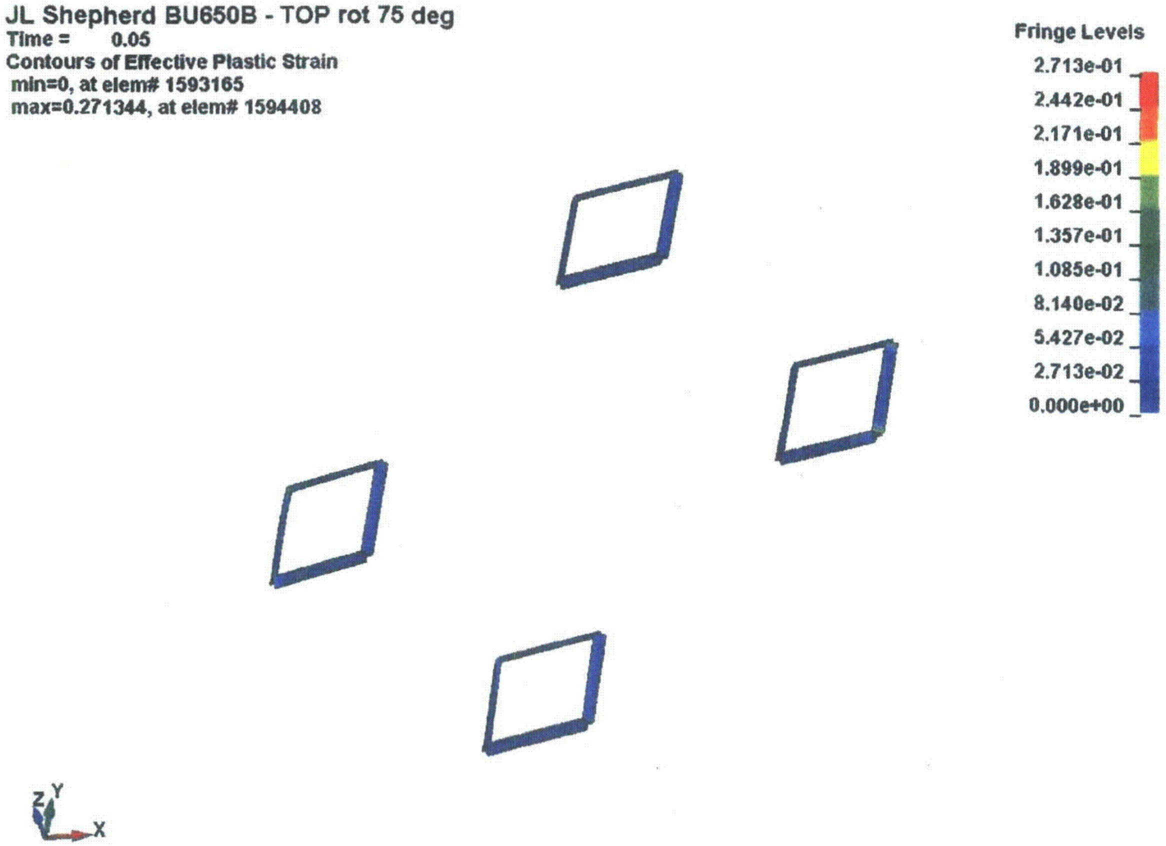

Figure 51: Part #114 – Mounting Bracket Welds: Max Plastic Strain 27.2%
(Rotated 15 degrees from Side Impact)

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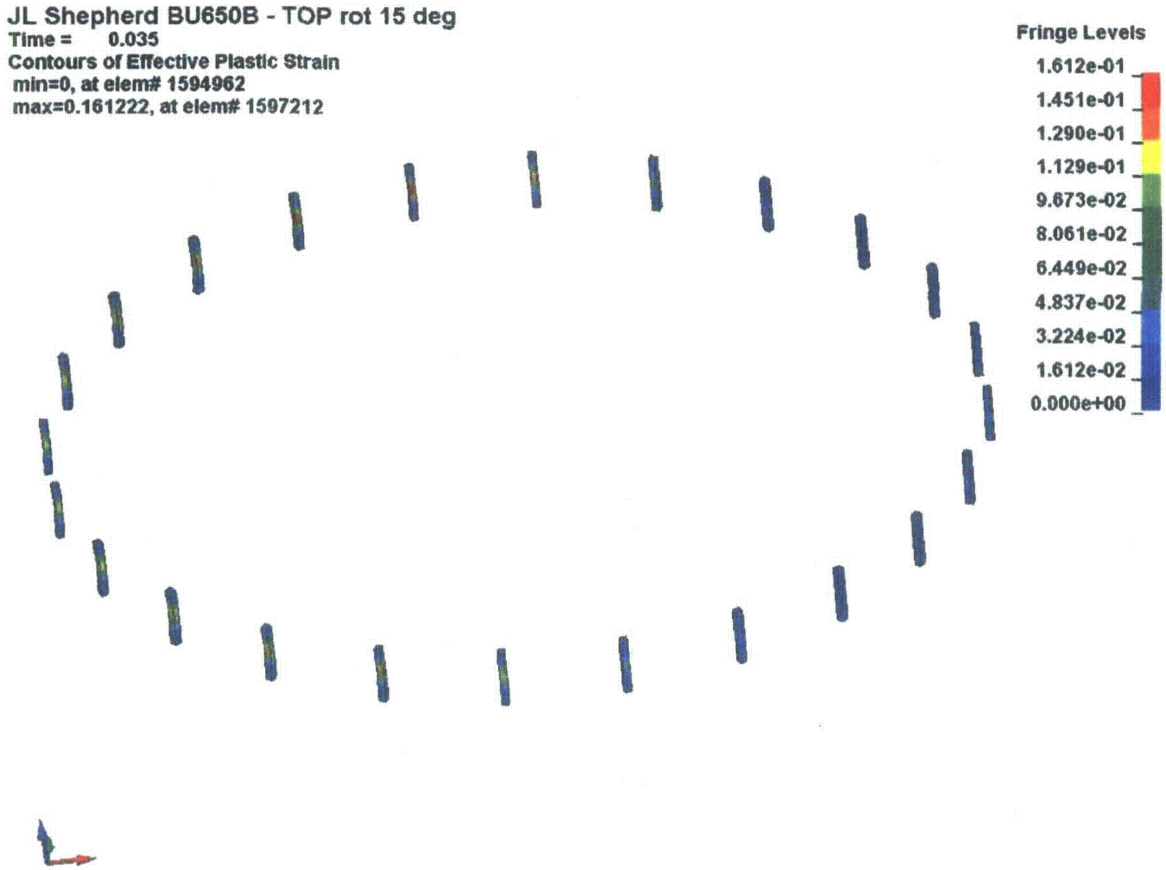

Figure 52: Part #119 – BU650B Body Closure Bolts Core Volumes: Max Plastic Strain 16.2% (Rotated 15 degree from Top Impact)

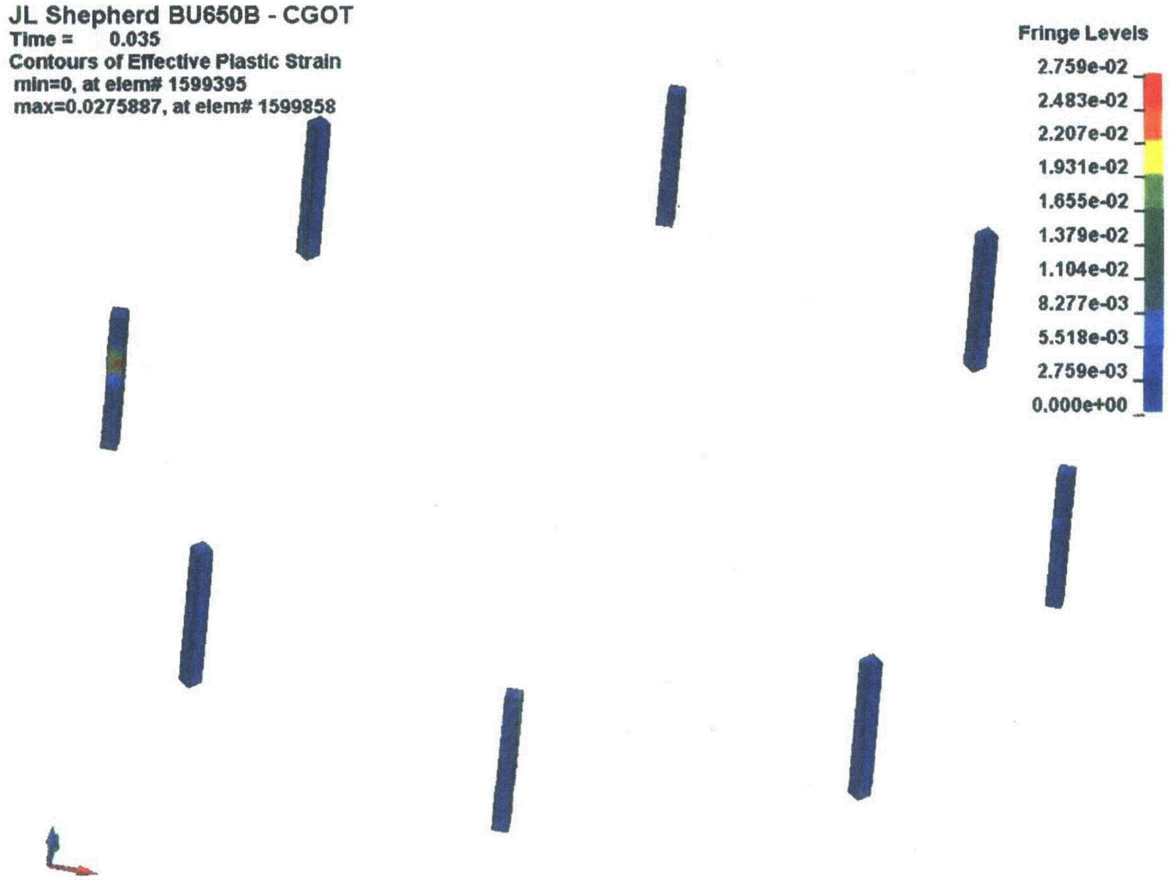

Figure 53: Part #121 – Shield Liner Closure Bolts Core Volumes: Max Plastic Strain 2.8% (45 degree Impact on Lid)

Figure 54: Part #124 – Shield Liner Impact Plate (Protects Bolts): Excessive Compressive Plastic Strain in Localized Areas (5 degrees rotated from Top Impact)

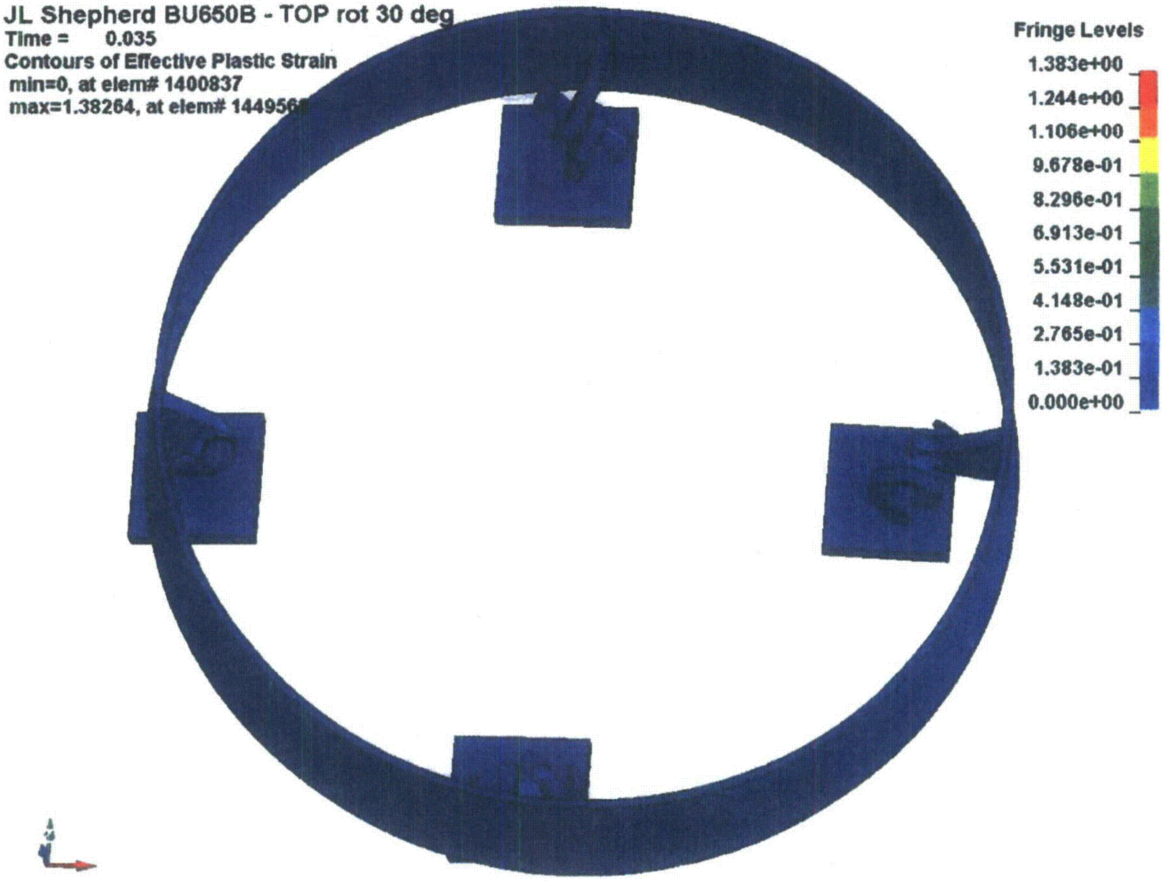

Figure 55: Impact Limiter Attachment Lugs, Mounting Plates and Ring (Parts #70, 72, 73, 112 and 113) (Rotated 30 degree from Top Impact)

DETAILED ANALYSIS OF 30 FT TOP DROP (ROTATED 15 DEG) WITH PUNCTURE

The BU650B worst case free drop orientation was identified previously as a 15 degree rotation from top impact using the plastic strain data of the outer body closure bolts from a simulated 30 ft free drop impact. Additional run data was obtained to identify the damage from the puncture impact (10 CFR 71.73 c 3) and immersion (21.7 psig external pressure, 10 CFR 71.73 c 5). The comparison of the plastic strain data from the change in the hourglass coefficient from 0.1 (default) to 0.05 is also documented in this section. Further detailed results of the BU650B packaging components are detailed in this section. Table 3 identifies the difference between the maximum plastic strain results in all model parts for the previously identified worse-case impact orientation of 15 degrees rotated from the top drop.

Part #	Part Identification	15 deg from Top Drop		Difference
		EQ.5 = 0.10 (Default)	EQ.5 = 0.05	
1	*Cask Body Outer Btm Plate*	2.33	**3.30**	0.97
2	Cask Body Inside Btm Plate	0.82	**0.86**	0.04
3	Cask Body Btm Plate Lip	0.43	**0.54**	0.11
4	Cask Body Outer Cylinder	0.63	**0.71**	0.08
5	Cask Body Inside Cylinder	1.37	**1.60**	0.23
6	Cask Body Top Closure Ring	14.47	**23.42**	8.95
8	Cask Body Welded Nut	17.79	**4.30**	-13.49
10	**Cask Outer Bolt**	16.53	16.57	0.04
12	Cask Body Washers	0.96	**1.19**	0.23
25	Cask Lid Bolting Plate	4.11	**5.10**	0.99
26	Cask Lid Mid Plate	1.28	**1.79**	0.51
27	Cask Lid Out Cyl	10.83	**12.30**	1.47
28	Cask Lid Ins Cyl	4.24	**4.50**	0.26
29	Cask Lid Top Plate	9.94	**12.02**	2.08
30	Cask Lid Out Cyl w/Weld	75.64	**67.35**	-8.29
31	Cask Lid Ins Plate	16.11	**17.61**	1.50
32	Cask Lid Ins Cyl w/Weld	21.06	**19.18**	-1.88
33	Inside Shoring	26.87	**31.97**	5.10
45	Impact Limiter Shell; Upp Horiz Plt	16.23	**15.63**	-0.60
47	Impact Limiter Shell; Ins Horiz Plt	25.69	**29.31**	3.62
49	Impact Limiter Shell; Mid Ins Vert Cyl	32.47	**33.95**	1.48
51	Impact Limiter Shell; Ins Vert Cyl	111.95	**52.44**	-59.51
53	Impact Limiter Shell; Out Vert Cyl	14.21	**10.25**	-3.96
55	Impact Limiter Shell; Btm Out Horiz Plt	16.86	**6.20**	-10.66
57	Impact Limiter Inner Angle	26.58	**31.49**	4.91
70	Lifting Ring; Impact Limiter	11.13	**15.50**	4.37
72	Bolting Lug; Impact Limiter	63.98	**65.24**	1.26
73	Pins; Cask Body / Impact Limiter	37.28	**37.96**	0.68
76	Shield Liner Shell	67.99	**85.33**	17.34
100	Shield Liner Lid Closure Shell	44.12	**35.20**	-8.92
106	**Shield Liner Bolts**	1.91	**2.63**	0.72
109	Shield Liner Washers	0.07	**0.95**	0.88
112	4x4 Mounting Bracket; Cask Body	5.61	**4.95**	-0.66
113	Mounting Bracket Lug; Cask Body	51.24	**54.78**	3.54
114	Mounting Brackets Welds	5.92	**7.22**	1.30
119	**Cask Body Bolts Core**	16.13	15.61	-0.52
121	***Shield Liner Bolts Core***	*0.80*	***1.21***	*0.41*
124	Impact Plate on Shield Liner	36.34	**40.38**	4.04

Table 3: Component Maximum Plastic Strains versus Hourglass Coefficients (EQ.5 0.10 and 0.05) (15 degree rotated from Top Drop Orientation)

Table 3 identifies the effect of the plastic strain results from the differing hourglass coefficient (EQ.5) from the default (0.10) to the value recommended by users (0.05) which minimizes the hourglassing phenomenon in highly distorted elements. The best reduction in hourglassing resulted in the impact limiter outer thin metal shell (part #51 for example). The majority of parts which have no or minimal hourglassing, resulted in very small changes in the plastic strain results with one example being the BU650B main body closure bolts, parts 10 and 119. Although the default EQ.5 hourglassing coefficient 0.1 was used to establish the worse-case free drop impact orientation, it is assumed the EQ.5 hourglassing coefficient 0.05 results as shown in Table 3 are the realistic results based on LS-DYNA user manual recommendations (LS-DYNA Keyword User's Manual, page 16.3, Reference 4).

Part #	Part Identification	15 deg from Top	
		Lid Punch	Side Punch
1	Cask Body Outer Btm Plate	3.75	5.72
2	Cask Body Inside Btm Plate	0.86	0.88
3	Cask Body Btm Plate Lip	0.53	0.54
4	Cask Body Outer Cylinder	0.72	3.93
5	Cask Body Inside Cylinder	1.60	1.60
6	Cask Body Top Closure Ring	21.61	23.22
8	Cask Body Welded Nut	4.46	3.55
10	**Cask Outer Bolt**	16.71	17.73
12	Cask Body Washers	1.11	1.18
25	Cask Lid Bolting Plate	5.08	5.10
26	Cask Lid Mid Plate	10.22	1.88
27	Cask Lid Out Cyl	13.02	13.12
28	Cask Lid Ins Cyl	5.72	4.71
29	Cask Lid Top Plate	15.38	11.98
30	Cask Lid Out Cyl w/Weld	68.56	68.83
31	Cask Lid Ins Plate	18.00	17.27
32	Cask Lid Ins Cyl w/Weld	20.83	19.47
33	Inside Shoring	40.65	40.12
45	Impact Limiter Shell; Upp Horiz Plt	15.46	15.60
47	Impact Limiter Shell; Ins Horiz Plt	30.36	30.46
49	Impact Limiter Shell; Mid Ins Vert Cyl	33.21	26.82
51	Impact Limiter Shell; Ins Vert Cyl	86.25	77.41
53	Impact Limiter Shell; Out Vert Cyl	9.20	9.09
55	Impact Limiter Shell; Btm Out Horiz Plt	6.20	6.16
57	Impact Limiter Inner Angle	37.51	36.59
70	Lifting Ring; Impact Limiter	19.07	28.67
72	Bolting Lug; Impact Limiter	69.01	66.41
73	Pins; Cask Body / Impact Limiter	38.57	38.07
76	Shield Liner Shell	109.08	87.22
91	Shield Liner Lead	3.73	3.70
100	Shield Liner Lid Closure Shell	39.19	39.41
104	Shield Liner Lid Lead	1.29	1.35
105	Shield Liner Content	0.00	0.00
106	**Shield Liner Bolts**	2.68	2.94
109	Shield Liner Washers	1.10	1.27
112	4x4 Mounting Bracket; Cask Body	4.95	4.96
113	Mounting Bracket Lug; Cask Body	57.24	55.39
114	Mounting Brackets Welds	8.04	8.24
119	**Cask Body Bolts Core**	15.73	15.82
121	**Shield Liner Bolts Core**	1.31	1.45
124	Impact Plate on Shield Liner	40.92	44.56

Table 4: BU650B Component Maximum Plastic Strains; Cumulative Damage from 30 ft Top Drop (rotated 15 deg) and 40 inch Puncture Drop (Lid and Side)

Table 4 identifies the maximum impact damage (true plastic strains) in the BU650B packaging components after the cumulative damage from the worse-case 30 ft Top Drop (rotated 15 degrees) and the 40 in puncture impact on the outer lid center and outer cylinder at mid height. Figures 56 through 58 show the cumulative plastic strain results after the puncture tests of both the outer lid and outer cylinder. The shortest gap distance between the inner and outer cylinders (Parts 4 & 5) was measured from LS-DYNA Prepost at ~ 1.65 inches between the two identified nodes (218588, 302393) in Figure 57.

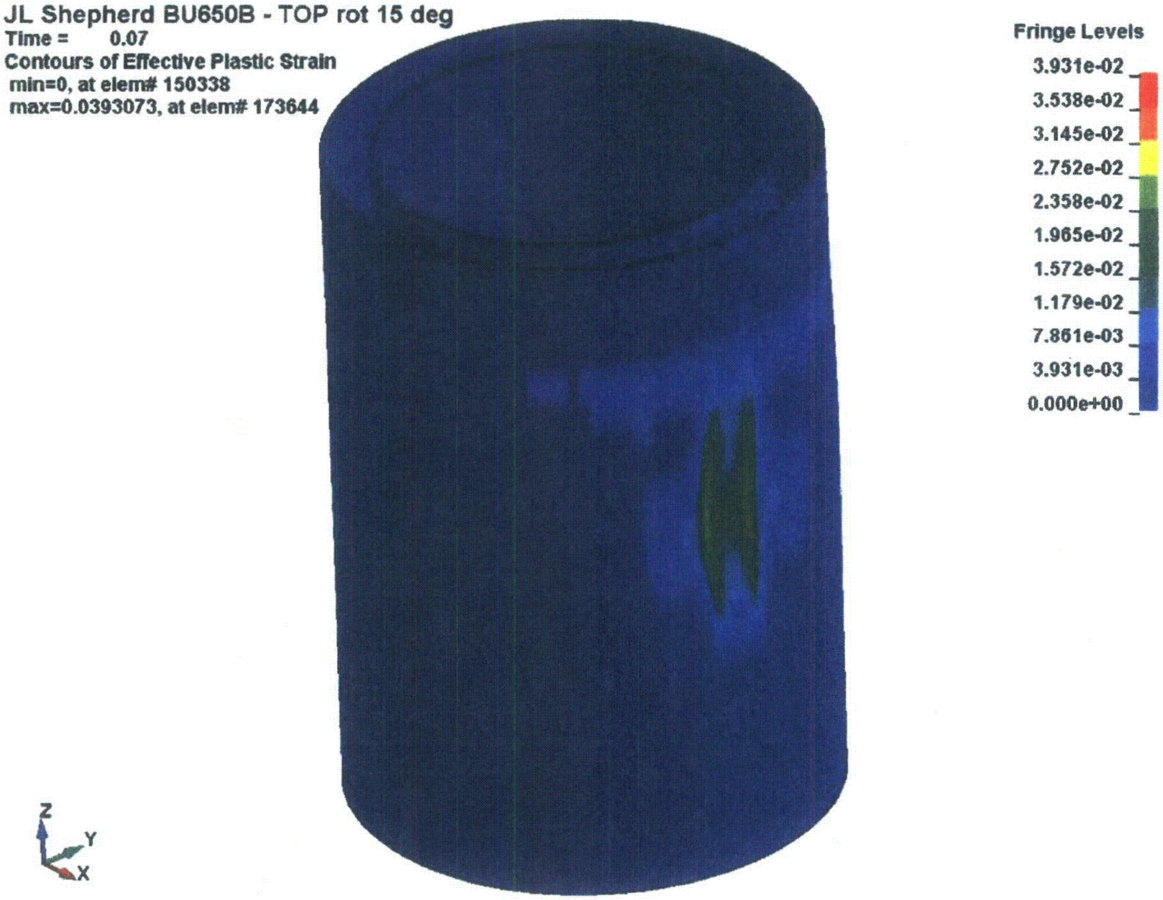

Figure 56: BU650B Inner and Outer Cylinder Cumulative Plastic Strain (3.94%) (Parts #4 & 5) (30 ft Top Impact rotated 15 degrees plus 40 in Side Puncture)

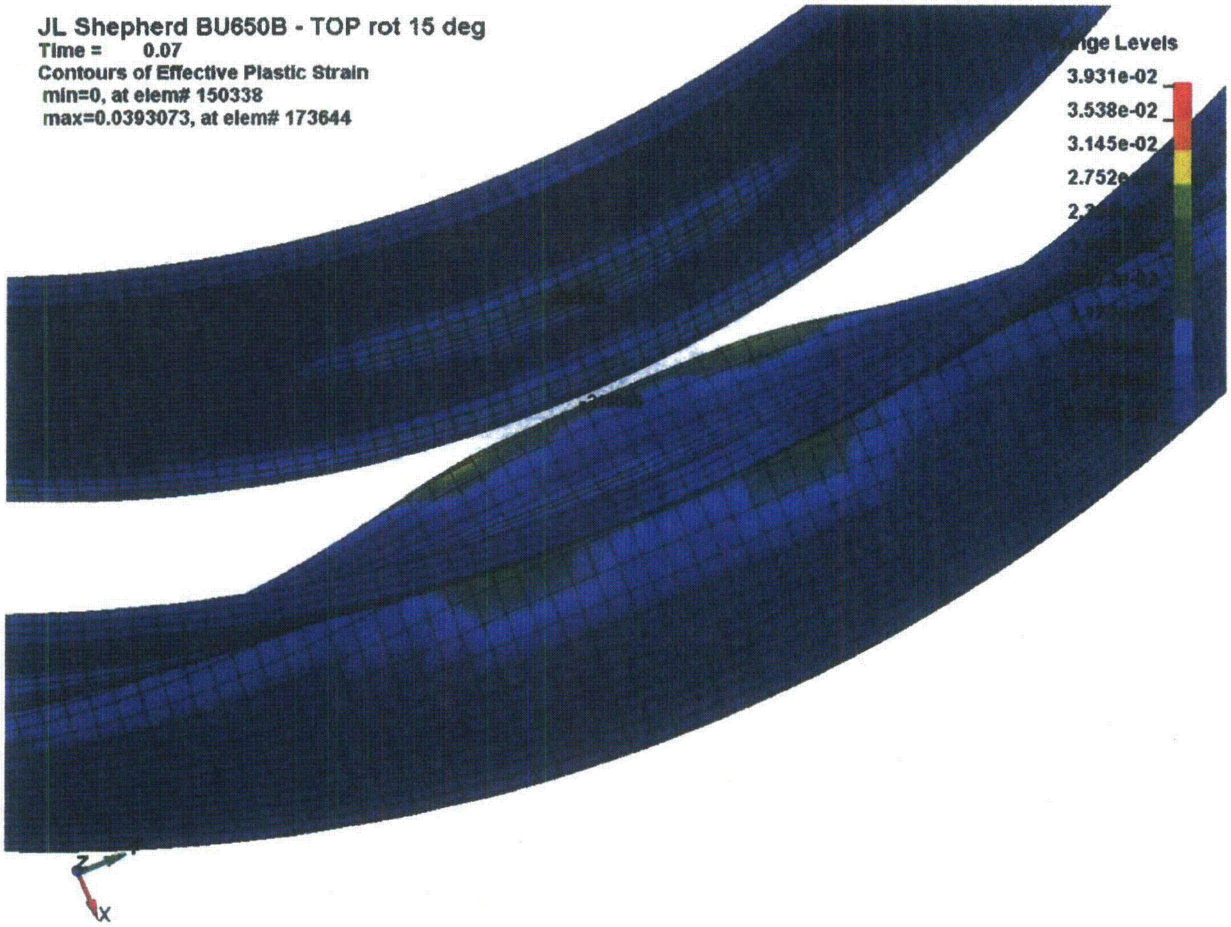

Figure 57: BU650B Inner and Outer Cylinder Minimum Distance is ~ 1.65 inch between Nodes 218588 and 302393 (Parts #4 & 5) (30 ft Top Impact rotated 15 degrees plus 40 in Side Puncture)

Figure 58: BU650B Lid Outer Plates (Parts #26 & 29)
(30 ft Top Impact rotated 15 degrees plus 40 in Top Puncture)

CONCLUSIONS / DISCUSSION OF RESULTS

All impact analyses discussed in this document were performed using LS-DYNA Version 971 (software properly verified by Y-12 QA Program) on a Dell Precision PWS670 (Intel Xeon) based Microsoft Windows XP computer. Table 4 identifies the true plastic strains (not engineering strains) of all components (excluding the foam and kaolite components) after the cumulative damage from a 30 ft Top Drop (rotated 15 degrees) and the 40 inch drop puncture both on the outer lid (center) and outer cylinder side. The final cumulative damage data shows the outer lid (Item 29) and outer cylinder (Item 4) will not be penetrated / ruptured into the kaolite region from the puncture test. This was expected since the impact limiters absorb the vast majority of the drop test energy and the kaolite at these puncture impact regions are not compacted prior to the puncture impacts.

The BU650B outer closure bolts are the single most important items which maintain confinement of the inner shield liner contents inside of the BU650B packaging after all cumulative HAC impact tests. Table 4 identifies the maximum true plastic strain value of from the outer closure bolts outer bolt materials (Items 10) and and inner core bolt volumes (Items 119) of 17.73% and 15.82%, respectively. Based on any comparison to the (true) strain at failure of the materials of these components, it is certain these bolts will not fail during HAC impact testing as modeled and contains adequate margin of safety. Also note these maximum plastic strains obtained and identified is the maximum in all bolts and not the average in each bolt or bolt material section.

The BU650B inner shield liner content closure bolts (Items 106 and 121) are the single most important items to maintain containment of the contents within the shield liner. The maximum (true) plastic strain values of 2.94% (outer bolt materials, Item 106) and 1.45% (inner bolt core volume, Item 121) from Table 4 identifies the worst-case orientation being the 30 ft Top Drop (rotated 15 degrees) and followed by the side puncture. Again, by any comparison to the (true) maximum plastic strains at failure of the bolt materials, these maximum (true) plastic strains in these shield liner bolts illustrate a large margin of safety against failure from the cumulative HAC 30 ft drop and puncture impacts.

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APPENDIX A
LS-DYNA Input File Data Lines for BU650B Impact Runs

```
*KEYWORD
*TITLE
JL Shepherd BU650B
$ - Begin Added Lines
$
*CONTROL_CONTACT
,,,1
,
*CONTROL_PARALLEL
2,,
*CONTROL_TERMINATION
0.035,,,,
*DATABASE_BINARY_D3PLOT
0.0004,,,,
*DATABASE_BINARY_RUNRSF
2000,
*DATABASE_SLEOUT
1.e-5,
*DATABASE_MATSUM
1.e-5,
*DATABASE_GLSTAT
1.e-5,
*CONTROL_ENERGY
2,,,
$
$ *DATABASE_RWFORCE
$ 1.e-5,
$
$ ******************************************
$
$ DEFINE GRAVITY - 386 in/s^2 (based on rotation of BU650B)
*LOAD_BODY_X
4,1,
*DEFINE_CURVE
4,
0.00, 33.7
100.00, 33.7
$
$ DEFINE GRAVITY
*LOAD_BODY_Z
5,1,
*DEFINE_CURVE
5,
0.00, 384.6
100.00, 384.6
$
$ END DEFINE GRAVITY
$
*CONTACT_AUTOMATIC_SINGLE_SURFACE_TITLE
35,TrueGrid Sliding Interface #        35
1,0,2,0,,,0,0
0.300,0.200,10.00E+00,0.000E+00,0.000E+00,0,0.000E+00,0.000E+00
0.000E+00,0.000E+00,0.000E+00,0.000E+00,0.000E+00,0.000E+00,0.000E+00,0.000E+00
2
0.000E+00,0,0,0,1
*SET_PART_LIST
1
 1, 2, 3, 4, 5, 6, 8,10,
12,13,25,26,27,28,29,30,
31,32,33,45,47,49,51,53,
55,57,63,70,72,73,76,91,
100,104,105,106,109,111,112,113,
114,118,119,121,124
$
$ ********************************************
$
$ *******************************************************
$
*SECTION_SOLID
1,1
$
$*SECTION_SHELL
$2,2,,3
$,
$
$ ***********************************************************
```

```
$
*HOURGLASS
1,5,
$
$ ************************************************************
$
$
$ Part #1
*PART
Cask Body Outside Btm Plate
1,1,1,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
1, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #2 - Cask Body Inside Btm Plate
*PART
Cask Body Inside Btm Plate
2,1,2,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
2, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #3 - Cask Body Inside Btm Plate Ext Lip
*PART
Cask Body Inside Btm Plate Ext Lip
3,1,3,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
3, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #4 - Cask Body Outer Cylinder Wall
*PART
Cask Body Outer Cylinder Wall
4,1,4,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
4, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #5 - Cask Body Inner Cylinder Wall
*PART
Cask Body Inner Cylinder Wall
5,1,5,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
5, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #6 - Cask Body Top Closure Ring
*PART
Cask Body Top Closure Ring
6,1,6,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
6, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #8 - Cask Bolts - Welded Nut
*PART
Cask Bolts - Welded Nut
8,1,8,,1
$ steel wrought stainless 316L bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
8, 7.5130E-4, 2.8E+7, 0.29, 135156., 0.22634

,
$ Part #10 - Cask Bolts - Bolt Shank
*PART
Cask Bolts - Bolt Shank
10,1,10,,1
$ steel wrought stainless 316L bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
10, 7.5130E-4, 2.8E+7, 0.29, 135156., 0.22634

,
$ Part #12 - Cask Bolts - Washer
*PART
Cask Bolts - Washer
12,1,12,,1
$ steel wrought stainless 316L bar annealed - STRAIN
```

```
*MAT_POWER_LAW_PLASTICITY
12, 7.5130E-4, 2.8E+7, 0.29, 135156., 0.22634
,
$ part #13 - Cask Body Kaolite - Side Cylinder
*PART
Drum Kaolite
13,1,13,,1
$ kaolite
*MAT_HONEYCOMB
13, 3.3583E-05, 1.0E+6, 0.01, 40000., 0.20,
$ assuming 22.4 lb/ft^3
3,
14811., 14811., 14811., 7405., 7405., 7405.,
,
,
$
*DEFINE_CURVE
3,
 0.00,  148.
 0.01,  148.
 0.10,  248.
 0.20,  317.
 0.30,  396.
 0.40,  523.
 0.50,  797.
 0.55,  1079.
 0.60,  1553.
 0.65,  2500.
 0.70,  5000.
 0.75,  10000.
 0.775, 20000.
 0.79,  30000.
 0.80,  40000.
$
$ Part #25 - Cask Lid Top Bolting Plate
*PART
Cask Lid Top Bolting Plate
25,1,25,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
25, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #26 - Cask Lid Middle Plate
*PART
Cask Lid Middle Plate
26,1,26,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
26, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #27 - Cask Lid Outside Cyl Wall
*PART
Cask Lid Outside Cyl Wall
27,1,27,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
27, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #28 - Cask Lid Inside Cyl Wall
*PART
Cask Lid Inside Cyl Wall
28,1,28,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
28, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #29 - Cask Lid Top Plate
*PART
Cask Lid Top Plate
29,1,29,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
29, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #30 - Cask Lid Outside Cyl Wall with weld
*PART
```

```
Cask Lid Outside Cyl Wall with weld
30,1,30,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
30, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #31 - Cask Lid Btm Inside Plate
*PART
Cask Lid Btm Inside Plate
31,1,31,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
31, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #32 - Cask Lid Inside Cyl with Weld
*PART
Cask Lid Inside Cyl with Weld
32,1,32,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
32, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #33 - Shoring
*PART
Shoring
33,1,33,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
33, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #45 - Impact Limiter Shell Upper Horiz Flat
*PART
Impact Limiter Shell Upper Horiz Flat
45,1,45,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
45, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #47 - Impact Limiter Shell Inside Horiz Flat
*PART
Impact Limiter Shell Inside Horiz Flat
47,1,47,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
47, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #49 - Impact Limiter Shell Inside Mid Cyl
*PART
Impact Limiter Shell Inside Mid Cyl
49,1,49,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
49, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #51 - Impact Limiter Shell Inner Cyl
*PART
Impact Limiter Shell Inner
51,1,51,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
51, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #53 - Impact Limiter Shell Outer Cyl
*PART
Impact Limiter Shell Outer Cyl
53,1,53,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
53, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #55 - Impact Limiter Shell Outer Flat
*PART
Impact Limiter Shell Outer Flat
55,1,55,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
```

```
55, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #57 - Impact Limiter Shell Inner Angle
*PART
Impact Limiter Shell Inner Angle
57,1,57,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
57, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ part #63 Impact Limiter Foam 12 pcf
*PART
Impact Limiter Foam
63,1,63,,1
$ foam
*MAT_HONEYCOMB
63, 1.797E-05, 6.0E+5, 0.01, 10000., 0.15,
1,1,2
12339., 12339., 13889., 3629.0, 3629.0, 3760.0,
,
,
$
*DEFINE_CURVE  $ 12 pcf general plastics last-a-foam-transverse
1,
0.00,      459
0.1,       459
0.2,       463
0.3,       483
0.4,       518
0.5,       622
0.6,       854
0.65,      1110
0.7,       1447
0.75,      2430
0.8,       4031
0.85,      10000
$
$
*DEFINE_CURVE  $ 12 pcf general plastics last-a-foam-parallel
2,
0.00,      465
0.1,       465
0.2,       471
0.3,       492
0.4,       526
0.5,       628
0.6,       856
0.65,      1099
0.7,       1407
0.75,      2478
0.8,       4093
0.85,      10000
$
$ Part #70 - Impact Limiter Lifting Ring
*PART
Impact Limiter Lifting Ring
70,1,70,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
70, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #72 - Impact Limiter Bolting Lug
*PART
Impact Limiter Bolting Lug
72,1,72,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
72, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #73 - Impact Limiter Attachment Pins
*PART
Impact Limiter Attachment Pins
73,1,73,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
73, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
```

```
,
$ Part #76 - Shield Liner #1 Shell
*PART
Shield Liner #1 Shell
76,1,76,,1
$ steel carbon AISI 1010 - STRAIN
*MAT_POWER_LAW_PLASTICITY
76, 7.3316E-4, 3.0E+7, 0.29, 77364., 0.18572

,
$ Part #91 - Shield Liner #1 Body Lead
*PART
Shield Liner #1 Body Lead
91,1,91,,1
$ Lead
*MAT_ISOTROPIC_ELASTIC_PLASTIC
91, 1.0645E-3, 7.2519E+5, 1740.45, 8702.26, 4.206E+6
$
$ Part #100 - Shield Liner #1 Lid Shell
*PART
Shield Liner #1 Lid Shell
100,1,100,,1
$ steel carbon AISI 1010 - STRAIN
*MAT_POWER_LAW_PLASTICITY
100, 7.3316E-4, 3.0E+7, 0.29, 77364., 0.18572

,
$ Part #104 - Shield Liner #1 Lid Lead
*PART
Shield Liner #1 Lid Lead
104,1,104,,1
$ Lead
*MAT_ISOTROPIC_ELASTIC_PLASTIC
104, 1.0645E-3, 7.2519E+5, 1740.45, 8702.26, 4.206E+6
$
$ Part #105 - Shield Liner #1 Content
*PART
Shield Liner #1 Content
105,1,105,,1
$ steel wrought stainless 304 bar annealed - STRAIN
$ 6.75" dia x 9" cylinder slug, 322.062 cubic inches
$ Density changed to match 25 lbs total weight
*MAT_POWER_LAW_PLASTICITY
105, 2.011E-4, 2.81E+7, 0.29, 162738., 0.27208

,
$ Part #106 - Shield Liner #1 Bolts
*PART
Shield Liner #1 Bolts
106,1,106,,1
$ JL Shepherd stated use Grade 5 bolts 80ksi Yield 100 ksi Ult
$ carbon steel AISI 1020 hardened used, 80 ksi Yield 104 ksi Ult - STRAIN
$ 490 lbs/cubic ft = 0.28356 lbs/in^3 / 386 = 7.3462E-4
*MAT_POWER_LAW_PLASTICITY
106, 7.3462E-4, 3.0E+7, 0.29, 156749., 0.1244

$ Part #109 - Shield Liner #1 Washers
*PART
Shield Liner #1 Washers
109,1,109,,1
$ carbon steel AISI 1020 hardened used, 80 ksi Yield 104 ksi Ult - STRAIN
$ 490 lbs/cubic ft = 0.28356 lbs/in^3 / 386 = 7.3462E-4
*MAT_POWER_LAW_PLASTICITY
109, 7.3575E-4, 3.0E+7, 0.29, 156749., 0.1244

,
$ part #111 - Cask Body Lid Kaolite
*PART
Cask Body Lid Kaolite
111,1,111,,1
$ kaolite
*MAT_HONEYCOMB
111, 3.3583E-05, 1.0E+6, 0.01, 40000., 0.20,
$ assuming 22.4 lb/ft^3
3,
14811., 14811., 14811., 7405., 7405., 7405.,

,
,
$
$ Part #112 - Cask Body Mounting Brackets
```

```
*PART
Cask Body Mounting Brackets
112,1,112,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
112, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #113 - Cask Body Mounting Lugs
*PART
Cask Body Mounting Lugs
113,1,113,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
113, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ Part #114 - Cask Body Mounting Plate Welds
*PART
Cask Body Mounting Plate Welds
114,1,114,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
114, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$ part #118 visual rigid plane
*PART
Target
118,1,118,,0,0
$ RIGID MATERIAL
*MAT_RIGID
118, 1.0E-6, 2.8E+7, 0.29,
1.0, 7, 7

$
$ Part #119 - Cask Bolts Core Volume
*PART
Cask Bolts - Core Volume
119,1,119,,1
$ steel wrought stainless 316L bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
119, 7.5130E-4, 2.8E+7, 0.29, 135156., 0.22634
,
$ Part #121 - Shield Liner Bolts Core Volume
*PART
Shield Liner Bolts Core Volume
121,1,121,,1
$ JL Shepherd stated use Grade 5 bolts 80ksi Yield 100 ksi Ult
$ carbon steel AISI 1020 hardened used, 80 ksi Yield 104 ksi Ult - STRAIN
$ 490 lbs/cubic ft = 0.28356 lbs/in^3 / 386 = 7.3462E-4
*MAT_POWER_LAW_PLASTICITY
121, 7.3462E-4, 3.0E+7, 0.29, 156749., 0.1244
,
$ Part #124 - Shield Liner Impact Plate to Protect Bolts
*PART
Impact Plate to Protect Bolts
124,1,124,,1
$ steel wrought stainless 304 bar annealed - STRAIN
*MAT_POWER_LAW_PLASTICITY
124, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
,
$
$ Preload in Cask Bolts
$ Bolt Stress = 23,919 psi
$
*DATABASE_CROSS_SECTION_PLANE_ID
1,Cask Bolts
2,0,0,73.8625,0,0,74.7625
21,0,73.8625,
$
*INITIAL_STRESS_SECTION
1,1,21,2
$
$
*DEFINE_CURVE
21,
0.0, 0.0
0.0004, 23919.
```

```
0.0008, 23919.
$
*SET_PART_LIST
2,
10,119
$
$
$ Preload in Shield Bolts
$ Bolt Stress = 21,239 psi
$
*DATABASE_CROSS_SECTION_PLANE_ID
2,Shield Bolts
3,0,0,48.9125,0,0,49.2125
8,0,48.9125,
$
*INITIAL_STRESS_SECTION
2,2,22,3
$
*DEFINE_CURVE
22,
0.0, 0.0
0.0004, 21239.
0.0008, 21239.
$
*SET_PART_LIST
3,
106,121
$
$ - End Added Lines
```

UNCONTROLLED

FABRICATION, ASSEMBLY,
AND
INSPECTION RECORD

BU650B
LOWER PACKAGE ASSEMBLY

J.L. Shepherd & Associates
1010 Arroyo Avenue
San Fernando, CA 91340

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Document Control Number: BU650B.20 - 1

Rev.	Originator	Engineering	Operations	Quality Assurance	Date
0	Obsolete	Obsolete	Obsolete	Obsolete	5-5-11
1	G. Brown 7/13/2011	m shepherd 07/14/2011	7/14/2011	7-14-11	7-12-11

TABLE OF CONTENTS

1.0 Purpose and Scope

The purpose of this Fabrication, Assembly, and Inspection Record is to define the materials, methods, special processes, and verifications of process integrity used in fabrication of this sub assembly in order to assure reliability of product, while utilizing a graded approach to safety.

2.0 References

2.1 J.L. Shepherd & Associates Quality Assurance Manual, U.S. NRC Docket No. 72-0122

2.2 QAM/QP 17.0, Quality Records

2.3 ASTM-A167

2.4 J.L. Shepherd & Associates Drawing Number BU650B-LPA.

2.5 ASME Section IX, Boiler and Pressure Vessel Code, Welding and Brazing Qualifications, where applicable

3.0 Responsibilities

3.1 **Internal or External Shop Manager**. Ensures the proper function and use of equipment and tools necessary for installation of the above described part or component. Provides trained personnel capable of required tasks.

3.2 **Internal or External Quality Assurance Manager**. Responsible for implementation of this work instruction. Responsibilities include verification of personnel training, compliance with the instructions contained herein, adherence to identified standards identified herein, and record keeping.

Note: While the responsibilities defined in this work instruction may be delegated, the overall responsibility shall always remain with the individual as described above. The delegation of responsibilities shall be defined in writing.

4.0 Procurement. Component parts, raw materials, and services used in the fabrication of this assembly are to be procured from Approved Vendors, under Quality Assurance approved procurement instructions. The provisions of 10CFR Part 21 apply to purchases made under this instruction and are identified in the Bill of Materials attached as Appendix A. Tools and expendable items, identified as such on the Bill of Materials, used in the fabrication of this assembly may be procured from known sources without Quality Assurance pre-approval.

4.1 **Bill of Materials**. See Appendix A.

4.2 **Inspection of Materials.** All items listed on Appendix A are subject to minimum Quality Assurance requirements, beginning with the reporting requirements of 10CFR Part 21. Specific instructions are issued with purchase orders and are relevant to the Quality Category Assessment related to each item.

4.3 **Quality Category Assessment (QCA).** QCA's are determined by Engineering, in accordance with a graded approach to safety. Consult QAM/QP 4.0 for definitions of relevant QCA definitions and identifiers.

5.0 **Assembly.** This assembly is fabricated from three sub-assemblies: The BU650B Closing Ring, The BU650B Inner Liner Assembly, and the BU650B Outer Shell. There are two additional assembly processes: Installation of Kaolite 1600 and closure of the exposed Kaolite.

5.1 **Preparation.** Review all procured items for compliance with information contained in purchase orders and identified in the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.

5.2 **Layout.** Locate the materials identified in paragraph 4.1, and layout as follows:
(See Drawing BU650B-LPA)

- BU650B Closing Ring Assembly
- BU650B Inner Liner
- BU650B Outer Shell
- 1/2" thick by 44.5" diameter disc

5.3 **Fabrication.**

5.3.1

- Break all edges
- Clean all surfaces
- Set BU650B Inner Liner on flat surface
- Place BU650B Closing Ring on open end of BU650B Inner Liner
- Align inner diameter of closing ring to inner diameter of Inner Liner
- Tack weld (MIG) at four to six locations on outer diameter of BU650B Inner Liner
- Weld complete
- Radiographically inspect welds
- Place BU650B Outer Shell over the BU650B Inner Liner and Closing Ring assembly
- Align BU650B Outer Shell edge with outer diameter of BU650B Closing Ring, making certain that the chamfered edges are in contact
- Weld complete
- Radiographically inspect all welds; all welds are to be full penetration welds

Verify installation and quality of welds; Record information at Appendix B.

5.3.2 Kaolite 1600 Installation

- Clean vacant space between BU650B Outer Shell and BU650B Inner Shell
- Mix Kaolite 1600 per manufacturer's instructions
- Slowly pour Kaolite 1600, filling void between inner and outer cylinders. Vibrate to allow air to escape. Fill complete
- Cure in oven according to manufacturer's instructions
- Verify cure process; (time and temperature)
- Verify Kaolite installation is void free
- Install 44.5" OD disc over exposed Kaolite
- Heli-arc weld complete; fillet dimension should be 3/8"; full penetration weld
- Verify weld via Radiographical inspection process

5.3.3 Identify BU650B Outer Shell Assembly as follows:

J.L. Shepherd & Associates
Model: BU650B
Serial Number: ____________

6.0 Records

6.1 Records generated as a result of this Fabrication, Assembly, and Inspection Record are considered Permanent Quality Records.

6.2 Individual Assembly and Inspection instructions are contained in the attached Fabrication, Assembly, and Inspection Record. See Appendix B.

7.0 Enclosures

7.1 Appendix A: Bill of Materials

7.2 Appendix B: Fabrication, Assembly, and Inspection Record

7.3 Revision Summary Listing

Appendix A:
BILL OF MATERIALS
BU650B-Lower Package Assembly

Item Description	Quantity	Dimensions	Specifications or Certifications Required	Purchase Conditions	Receiving Inspection Required?	QCA Level	Accept/Reject	Inspector's Name	Date
BU650B-Closing Ring Assembly	1 each	N/A	Per Assembly and Inspection Record	N/A	NO	A			
BU650B-Inner Liner	1 each	N/A	Per Assembly and Inspection Record	N/A	YES	A			
Kaolite 1600	As required	Per Calculation	Per Manufacturer's Specification; See Thermal Ceramics' Engineering Guide	10CFR Part 21, Certificate of Conformance, Right to Inspect	YES	A			
BU650B-Outer Shell	1 each	N/A	Per Assembly and Inspection Record	N/A	YES	A			

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APPENDIX B: FABRICATION, ASSEMBLY, AND INSPECTION RECORD

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Paragraph #	Description	Accept	Reject	Date
5.1	Review all procured items for compliance with information contained in purchase orders and identified on the Bill of Materials at Appendix A. All items should be complete and properly identified by receiving and receiving inspection. Annotate complete at Appendix B.			
5.2	Layout			
5.3 5.3.1	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.2	Operation Complete. Attach “pour” or “batch” data as appropriate. Attach weld specification and inspection results.			
5.3 5.3.3	Operation Complete.			
6.0	Relevant inspection documents attached. Weld process specification and weld inspection results.			

Rework Record:

UNCONTROLLED

Note the cause of any rejection and engineering approved rework below. Any rework requiring disassembly requires quality assurance approval prior to commencement of work. All rework must be documented in accordance with QAM/QP 15.0.

Operation #	Description of Rework	Accept	Reject	Date

Revision Summary Listing

DCR# 0146
7-12-2011
Previous Rev. 0
New Rev. 1

Section 5.2: 4th dot: Changed 43.625" to 44.5"

Section 5.3.2: 3rd dot: Changed "cover" to "Fill". Deleted end of sentence after the word "complete".

7th dot: Changed 43.625" to 44.5"

UNCONTROLLED

FABRICATION, ASSEMBLY
AND
INSPECTION RECORD

BU650B
OUTER SHELL

J.L. Shepherd & Associates
1010 Arroyo Avenue
San Fernando, CA 91340

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Document Control Number: BU650B.19 - 1

Rev.	Originator	Engineering	Operations	Quality Assurance	Date
0	Obsolete	Obsolete	Obsolete	Obsolete	5-5-11
1	7/13/2011	M. Shepherd 07/14/2011	7/14/2011	Shirley Needham 7-14-11	7-12-11

TABLE OF CONTENTS

1.0 Purpose and Scope

The purpose of this Fabrication, Assembly and Inspection Record is to define the materials, methods, special processes, and verifications of process integrity used in fabrication of this sub assembly in order to assure reliability of product, while utilizing a graded approach to safety.

2.0 References

2.1 J.L. Shepherd & Associates Quality Assurance Manual, U.S. NRC Docket No. 72-0122

2.2 QAM/QP 17.0, Quality Records

2.3 ASTM-A167

2.4 J.L. Shepherd & Associates Drawing Number BU650B-LP-5

2.5 J.L. Shepherd & Associates Drawing Number BU650B-LP-3

2.6 ASME Section IX, Boiler and Pressure Vessel Code, Welding and Brazing Qualifications, where applicable.

3.0 Responsibilities

3.1 **Internal or External Shop Manager**. Ensures the proper function and use of equipment and tools necessary for installation of the above described part or component. Provides trained personnel capable of performing required tasks.

3.2 **Internal or External Quality Assurance Manager.** Responsible for implementation of this work instruction. Responsibilities include verification of personnel training, compliance with the instructions contained herein, adherence to identified standards identified herein, and record keeping.

Note: While the responsibilities defined in this work instruction may be delegated, the overall responsibility shall always remain with the individual as described above. The delegation of responsibilities shall be defined in writing.

4.0 **Procurement.** Component parts, raw materials, and services used in the fabrication of this assembly are to be procured from Approved Vendors, under Quality Assurance approved procurement instructions. The provisions of 10CFR Part 21 apply to purchases made under this instruction and are identified in the Bill of Materials attached as Appendix A. Tools and expendable items, identified as such on the Bill of Materials, used in the fabrication of this assembly may be procured from known sources without Quality Assurance pre-approval.

4.1 **Bill of Materials**. See Appendix A.

4.2 **Inspection of Materials**. All items listed on Appendix A are subject to minimum Quality Assurance requirements, beginning with the reporting requirements of 10CFR Part 21. Specific instructions are issued with purchase orders and are relevant to the Quality Category Assessment related to each item.

4.3 **Quality Category Assessment (QCA).** QCA's are determined by Engineering, in accordance with a graded approach to safety. Consult QAM/QP 4.0 for definitions of relevant QCA definitions and identifiers.

5.0 **Assembly**. This assembly is fabricated from two procured items: 3/8" thick, 304 stainless steel plates, rolled and formed to create a 62.5" long cylinder, having an outer diameter of 44.5", and a 44.5" OD x ½" thick 304 stainless steel disc.

5.1 **Preparation.** Review all procured items for compliance with information contained in purchase orders and identified in the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.

5.2 **Layout.** Locate the materials identified in paragraph 4.1, and layout as follows; See Drawings BU650B-LP-3 and BU650B-LP-5.

- Three panels, 3/8" thick by ~47.33" x 62.5"
- ½" thick by 44.5" OD disc

5.3 Fabrication.

5.3.1
- Break all edges
- Clean all surfaces
- Chamfer panel edges on top and bottom, 3/16" x 45°
- Set on square surface and weld to form cylinder having a 44.5" OD
- Radiographic weld inspection required

5.3.2
- Locate ½" thick x 44.5" diameter disc
- Chamfer one side 3/16" x 45°
- Break edge on side opposite chamfer

Identify as BU650B-Outer Shell and Set aside.

Annotate complete. Verify installation and quality of weld. See Appendix B.

5.3.3 Assign Serial Number to BU650B-Outer Shell

5.3.4 Identify BU650B Outer Shell Assembly as follows:

Model: BU650B
Serial Number: ___________

6.0 Records

6.1 Records generated as a result of this Fabrication, Assembly, and Inspection Record are considered Permanent Quality Records.

6.2 Individual Assembly and Inspection instructions are contained in the attached Fabrication, Assembly, and Inspection Record. See Appendix B.

7.0 Enclosures

7.1 Appendix A: Bill of Materials

7.2 Appendix B: Fabrication, Assembly and Inspection Record

7.3 Revision Summary Listing

Appendix A:
BILL OF MATERIALS
BU650B-Outer Shell

Item Description	Quantity	Dimensions	Specifications or Certifications Required	Purchase Conditions	Receiving Inspection Required?	QCA Level	Accept/Reject	Inspector's Name	Date
304 Stainless Steel Plate, rolled and formed to 44.5" OD, fully welded seam	3 each	3/8" thick x 47.3" x 62.5"	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
304 Stainless Steel Disc	1 each	1/2" thick by 44.5" OD	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
All State 308 welding rod	Amount required	N/A	90,000 PSI or equivalent	N/A	YES	A			

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APPENDIX B: FABRICATION, ASSEMBLY, AND INSPECTION RECORD

Paragraph #	Description	Accept	Reject	Date
5.1	Review all procured items for compliance with information contained in purchase orders and identified on the Bill of Materials at Appendix A. All items should be complete and properly identified by receiving and receiving inspection. Annotate complete at Appendix B.			
5.2	Layout			
5.3 5.3.1	Operation Complete. Attach weld specification and weld inspection results, if applicable.			
5.3 5.3.2	Operation Complete.			
5.3 5.3.3	Operation Complete.			
6.0	Attach relevant inspection documents; Weld process specification and weld inspection results.			

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Rework Record:

Note the cause of any rejection and engineering approved rework below. Any rework requiring disassembly requires quality assurance approval prior to commencement of work. All rework must be documented in accordance with QAM/QP 15.0.

Operation #	Description of Rework	Accept	Reject	Date

UNCONTROLLED

Revision Summary Listing

DCR# 0146
7-12-2011
Previous Rev. 0
New Rev. 1

UNCONTROLLED

Section 5.0: Changed 63.375" to 62.5"
Changed 43.625" to 44.5"

Section 5.2: 1st dot: Changed 63 3/8" to 62.5"
2nd dot: Changed 43.625" to 44.5"
Deleted 3rd dot.

Section 5.3.1: Deleted last 3 dots.

Added Section 5.3.2: Locate ½" thick x 44.5" diameter disc
Chamfer one side 3/16" x 45°
Break edge on side opposite chamfer

Changed section 5.3.2 to 5.3.3 and 5.3.3 to 5.3.4

Appendix A: Bill of Materials
1st line item: Changed 63.375" to 62.5"
2nd line item: Deleted
3rd line item: Changed 43.625" to 44.5"

UNCONTROLLED

FABRICATION, ASSEMBLY,

AND

INSPECTION RECORD

BU650B INNER LINER

J. L. Shepherd & Associates
1010 Arroyo Avenue
San Fernando, CA 91340

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Rev.	Originator	Engineering	Operations	Quality Assurance	Date
0	B. Brown 5-5-11	B. Brown 5-5-11	5-12-11	5-13-11	5-5-11
		5/12/2011			
		5/12/11			
		5/12/11			

DOCUMENT CONTROL NUMBER: BU650B.18-1

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TABLE OF CONTENTS

1.0 Purpose and Scope

The purpose of this Fabrication, Assembly, and Inspection Record is to define the materials, methods, special processes, and verifications of process integrity used in fabrication of this sub assembly in order to ensure reliability of product, while utilizing a graded approach to safety.

2.0 References

2.1 J.L. Shepherd & Associates Quality Assurance Manual, U.S. NRC Docket No. 72-0122

2.2 QAM/QP 17.0, Quality Records

2.3 ASTM-A 167/ASTM-A240

2.4 J.L. Shepherd & Associates Drawing Number BU650B-LP-2

2.5 J.L. Shepherd & Associates Drawing Number BU650B-LP-4

2.6 ASME Section IX, Boiler and Pressure Vessel Code, Welding and Brazing Qualifications, where applicable

3.0 Responsibilities

3.1 **Internal or External Shop Manager.** Ensures the proper function and use of equipment and tools necessary for installation of the above described part or component. Provides trained personnel capable of performing required tasks.

3.2 **Internal or External Quality Assurance Manager.** Responsible for implementation of this work instruction. Responsibilities include verification of personnel training, compliance with the instructions contained herein, adherence to identified standards identified herein, and record keeping.

Note: While the responsibilities defined in this work instruction may be delegated, the overall responsibility shall always remain with the individual as described above. The delegation of responsibilities shall be defined in writing.

4.0 Procurement. Component parts, raw materials, and services used in the fabrication of this assembly are to be procured from Approved Vendors, under Quality Assurance approved procurement instructions. The provisions of 10CFR Part 21 apply to purchases made under this instruction and are identified in the Bill of Materials attached as Appendix A. Tools and expendable items, identified as such on the Bill of Materials, used in the fabrication of this assembly may be procured from known sources without Quality Assurance pre-approval.

4.1 **Bill of Materials.** See Appendix A.

4.2 **Inspection of Materials.** All items listed on Appendix A are subject to minimum Quality Assurance requirements, beginning with the reporting requirements of 10CFR Part 21. Specific instructions are issued with purchase orders and are relevant to the Quality Category Assessment related to each item.

4.3 **Quality Category Assessment (QCA).** QCA's are determined by Engineering in accordance with a graded approach to safety. Consult QAM/QP 4.0 for definitions of relevant QCA definitions and identifiers.

5.0 **Assembly.** This assembly is fabricated from two procured items: a 3/8" thick, 304 stainless steel plate, rolled and formed to create an inner diameter of 35" x 58" long cylinder; and a 36.5" OD x ½" thick 304 stainless steel disc.

5.1 **Preparation.** Review all procured items for compliance with information contained in purchase orders and identified in the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.

5.2 **Layout.** Locate the materials identified in paragraph 4.1, and layout as follows; See Drawings BU650B-LP-4 and BU650B-LP-2.

- 3/8" thick by 35.75" OD cylinder
- ½" thick by 36.5" OD disc

5.3 **Fabrication.**

5.3.1

- Break all edges
- Clean all surfaces
- Set on flat surface
- Set 36.5" OD disc on top of inner liner; verify alignment; approximately 3/8" edge all around
- Tack weld a minimum of four points to hold disc
- Verify alignment
- Weld complete; heli-arc weld
- Inspect weld via Radiographic method

Identify as BU650B-Inner Liner and set aside.

Annotate complete. Verify installation and quality of weld. See Appendix B.

5.3.2 Assign Serial Number to BU650B-Inner Liner

5.3.3 Identify Inner Liner Assembly as follows:

Model: BU650B
Serial Number: ___________

6.0 Records

6.1 Records generated as a result of this Assembly and Inspection Record is considered Permanent Quality Records.

6.2 Individual Fabrication, Assembly, and Inspection instructions are contained in the attached Fabrication, Assembl, and Inspection Record. See Appendix B.

7.0 Enclosures

7.1 Appendix A: Bill of Materials

7.2 Appendix B: Fabrication, Assembly and Inspection Record

Appendix A:
BILL OF MATERIALS
BU650B-Inner Liner

Item Description	Quantity	Dimensions	Specifications or Certifications Required	Purchase Conditions	Receiving Inspection Required?	QCA Level	Accept/Reject	Inspector's Name	Date
304 Stainless Steel Plate, Rolled and Formed to 35.75" OD, Fully Welded Seam	1 each	3/8" thick x 35.75" OD x 58" long	ASTM A167 or ASTM A240	10CFR Part 21; Mill Certificate; Right to inspect	YES	A			
304 Stainless Steel Disc	1 each	1/2" thick x 36.5" Diameter	ASTM A167 or ASTM A240	10CFR Part 21; Mill Certificate; Right to inspect	YES	A			
All State 308 Welding Rod	Amount Required	N/A	90,000PSI or equivalent	N/A	YES	A			

APPENDIX B: FABRICATION, ASSEMBLY, AND INSPECTION RECORD

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Paragraph #	Description	Accept	Reject	Date
5.1	Review all procured items for compliance with information contained in purchase orders and identified on the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.			
5.2	Layout			
5.3 5.3.1	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.2	Operation Complete.			
5.3 5.3.3	Operation Complete.			
6.0	Relevant Inspection Documents Attached. Weld Process Specification and Weld Inspection Results			

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Rework Record:

Note the cause of any rejection and engineering approved rework below. Any rework requiring disassembly requires quality assurance approval prior to commencement of work. All rework must be documented in accordance with QAM/QP 15.0.

Operation #	Description of Rework	Accept	Reject	Date

UNCONTROLLED

FABRICATION, ASSEMBLY,

AND

INSPECTION RECORD

BU650B CLOSING RING

J. L. Shepherd & Associates
1010 Arroyo Avenue
San Fernando, CA 91340

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Rev.	Originator	Engineering	Operations	Quality Assurance	Date
0	B. Brown 5-5-11	B. Brown 5-5-11	5-12-11	Shirley Needham 5-13-11	5-5-11
		M Shepherd 5/12/2011			
		5/12/11			
		D. Shepherd 5/12/11			

DOCUMENT CONTROL NUMBER:
BU650B.17-1

TABLE OF CONTENTS

1.0 Purpose and Scope

The purpose of this Fabrication, Assembly, and Inspection Record is to define the materials, methods, special processes, and verifications of process integrity used in fabrication of this sub-assembly in order to assure reliability of product, while utilizing a graded approach to safety.

2.0 References

2.1 J.L. Shepherd & Associates Quality Assurance Manual, U.S. NRC Docket No. 72-0122

2.2 QAM/QP 17.0, Quality Records

2.3 ASTM-A167

2.4 J.L. Shepherd & Associates Drawing Number BU650B-LP-1

2.5 J.L. Shepherd & Associates Drawing Number BU650B-STUD

2.6 ASME Section IX, Boiler and Pressure Vessel Code, Welding and Brazing Qualifications, where applicable

3.0 Responsibilities

3.1 **Internal or External Shop Manager.** Ensures the proper function and use of equipment and tools necessary for installation of the above described part or component. Provides trained personnel capable of performing tasks.

3.2 **Internal or External Quality Assurance Manager.** Responsible for implementation of this work instruction. Responsibilities include verification of personnel training, compliance with the instructions contained herein, adherence to identified standards identified herein, and record keeping.

Note: While the responsibilities defined in this work instruction may be delegated, the overall responsibility shall always remain with the individual as described above. The delegation of responsibilities shall be defined in writing.

4.0 **Procurement**. Component parts, raw materials, and services used in the fabrication of this assembly are to be procured from Approved Vendors, under Quality Assurance approved procurement instructions. The provisions of 10CFR Part 21 apply to purchases made under this instruction and are identified in the Bill of Materials attached as Appendix A. Tools and expendable items, identified as such on the Bill of Materials, used in the fabrication of this assembly may be procured from known sources without Quality Assurance pre-approval.

4.1 **Bill of Materials.** See Appendix A.

4.2 **Inspection of Materials.** All items listed on Appendix A are subject to minimum Quality Assurance requirements, beginning with the reporting requirements of 10CFR Part 21. Specific instructions are issued with purchase orders and are relevant to the Quality Category Assessment related to each item.

4.3 **Quality Category Assessment (QCA).** QCA's are determined by Engineering, in accordance with a graded approach to safety. Consult QAM/QP 4.0 for definitions of relevant QCA definitions and identifiers.

5.0 **Assembly**. This assembly is fabricated in a series of sub-assemblies which are ultimately joined together to complete and end item, the BU650B Lower Package Assembly.

5.1 **Preparation.** Review all procured items for compliance with information contained in purchase orders and identified in the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.

5.2 **Layout.** Locate the materials identified in paragraph 4.1, and layout as follows:
(See Drawing BU650B-LP-1)

- ½" thick by 44.5" OD disc
- 52" long by 1.5" diameter, 316L Stainless Steel Rod

5.3 **Fabrication.**

5.3.1

- Break all edges on ½" thick disc
- Clean all surfaces on ½"thick disc
- Mark Zero (0°) and 180° axis (vertical)
- Mark 39.75" Bolt Circle
- Laser-cut or EDM 35" ID
- Drill .81" diameter through 24 equal spaces; use a step drill process, beginning at ¼"
- Machine or saw-cut, 1.5" diameter 316L Stainless Steel Rod as follows:
  - 24 pieces, 1.5" long
  - 24 pieces, 1/8" long x 1.25" diameter
- Drill and tap, ¾" – 10UNC each of the 1.5" long pieces
- Using ¾" – 10UNC Bolt, insert bolt through .81" diameter hole in 44.5" disc and attach threaded pieces. Weld threaded piece to plate. Repeat until all pieces are welded to plate.
- Remove bolt
- Break all hole edges
- Weld 1.25" diameter disc to bottom of each threaded piece
- Inspect welds via Magnetic Particle or Liquid Dye Penetrate method
- Chamfer bottom of Closing Ring ¼" x 45°

Identify as BU650B-Closing Ring and Set aside.
Annotate complete. Verify location of Ring, location of weld, and quality of weld (See Appendix B).

5.3.2 Assign Serial Number to BU650-Closing Ring

5.3.3 Identify Closing Ring Assembly as follows:

Model: BU650B
Serial Number: ____________

6.0 Records

6.1 Records generated as a result of this Fabrication, Assembly, and Inspection Record is considered Permanent Quality Records.

6.2 Individual Assembly and Inspection instructions are contained in the attached Fabrication, Assembly, and Inspection Record. See Appendix B.

7.0 Enclosures

7.1 Appendix A: Bill of Materials

7.2 Appendix B: Fabrication, Assembly, and Inspection Record

Appendix A:
BILL OF MATERIALS
BU650B-Closing Ring

Item Description	Quantity	Dimensions	Specifications or Certifications Required	Purchase Conditions	Receiving Inspection Required?	QCA Level	Accept/Reject	Inspector's Name	Date
304 Stainless Steel Ring	1 each	½" thick x 44.5" OD x 35" ID	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
316L Stainless Steel Rod	52"	1.5" diameter x 52" long	ASTM A276 or ASTM A479	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
316 Stainless Steel Lock Washer	3 packages	¾" x 1.27"	McMaster Carr Part# 92147A036 or equivalent	Catalog item; verify compliance with description	YES	C			
316 Stainless Steel Bolt	24 each	¾" - 10UNC x 2.0"	McMaster Carr Part Number 93190A892 or equivalent	Catalog item; verify compliance with description	YES	A			

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APPENDIX B: FABRICATION, ASSEMBLY, AND INSPECTION RECORD

UNCONTROLLED

Paragraph #	Description	Accept	Reject	Date
5.1	Review all procured items for compliance with information contained in purchase orders and identified on the Bill of Materials at Appendix A. All items should be complete and properly identified by receiving and receiving inspection. Annotate complete at Appendix B.			
5.2	Layout			
5.3 5.3.1	Operation Complete. Attach weld specification and weld inspection results, if appropriate.			
5.3 5.3.2	Operation Complete.			
5.3 5.3.3	Operation Complete.			
6.0	Relevant inspection documents attached. Weld process specification and weld inspection results, if appropriate.			

Rework Record:

Note the cause of any rejection and engineering approved rework below. Any rework requiring disassembly requires quality assurance approval prior to commencement of work. All rework must be documented in accordance with QAM/QP 15.0.

Operation #	Description of Rework	Accept	Reject	Date

FABRICATION, ASSEMBLY,

AND

INSPECTION RECORD

BU650B LID ASSEMBLY

J. L. Shepherd & Associates
1010 Arroyo Avenue
San Fernando, CA 91340

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Rev.	Originator	Engineering	Operations	Quality Assurance	Date
0	B. Brown 5-5-11	B. Brown 5-5-11	5-12-11	Shirley 5-13-11	5-5-11
		M Shepherd 5/12/2011			
		5/12/11			
		D. Shepherd 5/12/11			

DOCUMENT CONTROL NUMBER: BU650B.15-1

TABLE OF CONTENTS

1.0 Purpose and Scope

The purpose of this Fabrication, Assembly and Inspection Record is to define the materials, methods of fabrication, and special processes used in fabrication and verifications of process integrity in order to ensure reliability of product, while utilizing a graded approach to safety.

2.0 References

2.1 J.L. Shepherd & Associates Quality Assurance Manual, U.S. NRC Docket No. 72-0122.

2.2 QAM/QP 17.0, Quality Records.

2.3 Thermal Ceramics Kaolite 1600® Lightweight Castable Product Guide.

2.4 ASTM-A167/ASTM A240.

2.5 J.L. Shepherd & Associates Drawing Number BU650B-LA; and BU650B-LA-1 through BU650B-LA-5.

2.6 ASME Section IX, Boiler and Pressure Vessel Code, Welding and Brazing Qualifications.

3.0 Responsibilities

3.1 **Internal or External Shop Manager**. Ensures the proper function and use of equipment and tools necessary for installation of the above described part or component. Provides trained personnel capable of ensuring adequate fabrication and inspection of processes.

3.2 **Internal or External Quality Assurance Manager**. Responsible for implementation of this work instruction. Responsibilities include verification of personnel training, compliance with the instructions contained herein, adherence to identified standards identified herein, and record keeping.

Note: While the responsibilities defined in this work instruction may be delegated, the overall responsibility shall always remain with the individual as described above. The delegation of responsibilities shall be defined in writing.

4.0 **Procurement**. Component parts, raw materials, and services used in the fabrication of this assembly are to be procured from Approved Vendors, under Quality Assurance approved procurement instructions. The provisions of 10CFR Part 21 apply to purchases made under this instruction and are identified in the Bill of Materials attached as Appendix A. Tools and expendable items, identified as such on the Bill of Materials, used in the fabrication of this assembly may be procured from known sources without Quality Assurance pre-approval.

4.1 **Bill of Materials**. See Appendix A.

4.2 **Inspection of Materials**. All items listed on Appendix A are subject to minimum Quality Assurance requirements, beginning with the reporting requirements of 10CFR Part 21. Specific instructions are issued with purchase orders and are relevant to the Quality Category Assessment related to each item.

4.3 **Quality Category Assessment (QCA).** QCA's are made relevant to an item's importance to safety as determined by Engineering, utilizing a graded approach to safety. Consult QAM/QP 4.0 for definitions of relevant QCA definitions and identifiers.

5.0 **Assembly**. This assembly is fabricated in a series of sub-assemblies which are ultimately joined together to complete an end item, the BU650B Lid Assembly.

5.1 **Preparation**. Review all procured items for compliance with information contained in purchase orders and identified in the Bill of Materials at Appendix A. All items should be complete and properly identified by Receiving and Receiving Inspection. Annotate complete at Appendix B.

5.2 **Layout**. Locate the materials identified in paragraph 4.1, and layout as follows:

Group 1: Top of Lid (Drawings BU650B-LA, BU650B-LA-3 and BU650B-LA-4)

- ¼" thick by 2" high, by 36.75" diameter cylinder
- ¼" thick by 36.5" diameter disc
- Hoist ring
- ½" thick by 6" X 6" plate
- 2 ea. ½" -13UNC x 1.25" Socket Head Cap Screws
- Silicone Sealant, General Purpose

Group 2: Middle Lid (Drawing BU650B-LA-1)

- ½" thick by 44.5" Diameter Disc

Group 3: (Drawing BU650B-LA-5 and BU650B-LA-2)

- ¼" thick by 4" high, by 34.75" diameter cylinder
- ½" thick by 34.5" diameter disc

Annotate when complete at Appendix B

5.3 **Fabrication.**

5.3.1
- Break all edges
- Clean all contact surfaces in preparation for welding
- Mark center of ¼" thick by 36.5" OD disc

- Mark center of ½" thick by 6" X 6" plate
- Align centers of both plates and heli-arc weld perimeter of 6" X 6" plate
- Locate and mark mounting holes for lifting ring
- Drill to accommodate ½" – 13 UNC Tap, 2 places
- Tap ½"-13 UNC through, 2 places
- Using bolts provided, install Hoist Ring to center of 36.5" diameter plate
- Torque Socket Heat Cap Screws to 35 +/- 5 ft lbs.
- Apply Silicone Sealant to cap screw counter bores and fill to level surface
- Set 36.5" OD plate atop 36.5" outer diameter cylinder and weld complete, per specification
- Visually inspect weld. NDT Liquid Dye Penetrate or Mag Particle

Identify as BU650B-LID-5.1 and Set aside.

Annotate when complete. Verify all markings, hole locations, thread installation, and welding.

5.3.2 Locate ½" thick by 44.5" disc (Drawing BU650B-LA-1)

- Break all edges
- Clean all contact surfaces in preparation for marking and welding
- Find center of disc
- Mark 19.875" radius (Bolt circle). Mark this side as "TOP"
- Mark 18.375" radius on same side
- Locate 24 ea hole centers on 19.875" bolt circle
- Drill ¼" pilot hole, 24 places, evenly spaced, using HS Drill
- Drill .812" dia. 24 places, evenly spaced, through
- Chamfer 1/16 X 45 Deg; all holes (24 places)
- Turn disc over and mark a 17.375" radius on bottom side

Set BU650B-LID-5.1 assembly, with lifting ring facing up, on 18.375" radius marking and weld to ½" thick by 44.5" disc, per specification.

- Inspect weld via NDT Liquid Dye Penetrate Method.

Annotate when complete. Verify all markings, hole locations, and welding. See Appendix B.

5.3.3 Locate ¼" thick, by 4" high, by 34.75" diameter cylinder. (Drawing BU650B-LA-5)

- Break all edges
- Clean all surfaces

5.3.4 Invert BU650B-LID-5.1 assembly so that 34.75" circle markings are visible. Set on blocks to ensure flatness of surface.

- Set ¼" thick, by 4" high, by 34.75" diameter cylinder on marked circle
- Weld <u>inside</u> of ring to ½" plate.
- Heli-arc weld complete

- Inspect via NDT Liquid Dye Penetrate method

Annotate complete. Verify location of ring, location of weld, and quality of weld. See Appendix B.

5.3.5 Assign Serial Number to BU650B-LID

5.3.6 Installation of Kaolite-1600

Vendor Process. Vendor must be approved by Quality Assurance or process requires Engineering Verification of 100% of all activities.

- Mix and pour, per manufacturer's instructions, a sufficient amount of Kaolite 1600 to fill the 4" cylinder completely
- Cure Kaolite 1600 mixture in a controlled oven by raising the oven temperature to 225° Fahrenheit and expose for no less than six hours
- Verify all vendor processes and controls. Record information at Appendix B
- Cover exposed Kaolite 1600 with plywood, restrain with straps, and return BU650B Lid Assembly to weld process shop for completion

5.3.7 Assembly completion

- Locate ½" thick by 34.5" outer diameter disc
- Break all edges
- Clean all surfaces being careful not to contaminate Kaolite 1600
- Cover exposed Kaolite 1600 with 34.5" diameter disc and weld complete to ¼" cylinder
- Inspect via Magnetic Particle or Liquid Dye Penetrate method

5.3.8 Identify Lid Assembly as follows:

Model: BU650B
Serial Number: ____________

5.3.9 Stencil/Label lifting ring with the following: "FOR REMOVAL OF LID ONLY". Annotate completion of all assembly items. Record Serial Number where required.

6.0 Records

6.1 Records generated as a result of this Assembly and Inspection Record are considered Permanent Quality Records.

6.2 Individual Assembly and Inspection instructions are contained in the attached Fabrication, Assembly, and Inspection Record. See Appendix B.

7.0 Enclosures

7.1 Appendix A: Bill of Materials

7.2 Appendix B: Fabrication, Assembly, and Inspection Record

Appendix A:
BILL OF MATERIALS
BU650B-LID Assembly

Item Description	Quantity	Dimensions	Specifications or Certifications Required	Purchase Conditions	Receiving Inspection Required?	QCA Level	Accept/Reject	Inspectors Name	Date
304 Stainless Steel Cylinder	1 each	¼" Thick x 2" High x 36.75 OD	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
304 Stainless Steel Disc	1 each	¼" Thick x 36.5" Diameter Disc	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
304 Stainless Steel Disc	1 each	½" Thick x 44.5" Diameter Disc	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
304 Stainless Steel Disc	1 each	½" Thick x 34.5" Diameter Disk	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
304 Stainless Steel Plate	1 each	½" Thick x 6" x 6"	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
Hoist Ring	1 each	McMaster Carr Part# 29505T23 or equivalent	5,000 lb. Lifting capacity	Limited to Catalog certifications only; catalog item	YES	B			
Cap Screw Black Oxide	2 each	½" – 13 UNC by 1.25" long	McMaster Carr Part# 91251A714 or equivalent	Limited to Catalog certifications only; catalog item	YES	B			
304 Stainless Steel Cylinder	1 each	¼" Thick x 4" High x 34.75" OD	ASTM A167 or ASTM A240	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
Kaolite 1600	As needed	Approximately 2.15 Cubic Feet	Per engineering specifications. See Thermal Ceramics Engineer Guide.	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			
Silicone Sealant	1 Tube	None	General Purpose	Potting Compound	NO	C			
Welding Rod	As required	As Required	All State 308L or equivalent.	10 CFR Part 21 Mill Certifications Right to inspect	YES	A			

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APPENDIX B: FABRICATION, ASSEMBLY, AND INSPECTION RECORD

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Paragraph #	Description	Accept	Reject	Date
5.1	Review all procured items for compliance with information contained in purchase orders and identified on the Bill of Materials at Appendix A. All items should be complete and properly identified by receiving and receiving inspection. Annotate complete at Appendix B.			
5.2	Layout - Group 1			
	Layout – Group 2			
	Layout – Group 3			
5.3 5.3.1	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.2	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.3	Operation Complete.			
5.3 5.3.4	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.5	Operation Complete.			
5.3 5.3.6	Operation Complete. Attach lot/batch mix information and oven cure information.			
5.3 5.3.7	Operation Complete. Attach weld specification and weld inspection results.			
5.3 5.3.8	Operation Complete.			
5.3 5.3.9	Operation Complete.			
6.0	Attach records and certificates.			

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Rework Record:

Note the cause of any rejection and engineering approved rework below. Any rework requiring disassembly requires quality assurance approval prior to commencement of work. All rework must be documented in accordance with QAM/QP 15.0.

Operation #	Description of Rework	Accept	Reject	Date

SPECIFICATION

FOR

INSTALLATION, INSPECTION, AND TESTING OF RIGID, CLOSED-CELL, POLYURETHANE FOAM

UTILIZED WITHIN

BU650B CASK ASSEMBY IMPACT LIMITERS

CONTROLLED DOCUMENT

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Rev.	Originator		Verified by:		Quality Assurance Review Performed By:	Date
0	W.H. Brown		M. Brownstein		W.H. Brown	6-20-08
1	W.H. Brown		M. Brownstein		W.H. Brown	6-25-08
2	W.H. Brown		M. Brownstein		W.H. Brown	12-9-09
3	W.H. Brown 6/7/12		M. Brownstein Martin Brownstein 6/10/12		Shirley Needham 6/7/12 Shirley Needham	6-7-12

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1.0 SCOPE

1.1 Purpose

This specification outlines the requirements for installation, inspection, and testing of rigid, closed-cell, polyurethane foam utilized within the BU650B Impact Limiter Assemblies. These items may be fabricated at vendor(s), accepted by QC and Engineering only. The vendor of preference is General Plastics Manufacturing Company, 4910 Burlington Way, Tacoma, Washington.

1.2 Applicability

This specification shall apply to all organizations involved with installation, inspection and testing of rigid, closed-cell polyurethane foam utilized within the JL Shepherd BU650B Impact Limiter Assembly.

1.3 Prerequisites

A survey of the vendor's Quality Assurance Program is required prior to installation of foam. Site visit and/or surveillance of installation, inspection, and testing activities of vendor are at the option of JLS&A Quality Assurance.

1.4 Definitions

1.4.1 Authorized JL Shepherd Representatives:

William H. Brown
BU650B Project Manager

Que Pho
Operations Manager, Assistant Project Manager

1.4.2 Approval: A written statement from an Authorized J.L. Shepherd Representative.

1.4.3 Certificate of Compliance: A written statement, signed by a qualified vendor, attesting that the items or services defined herein are in accordance with specified requirements of this Engineering Specification and accompanied by any additional information necessary to substantiate the statement.

1.4.4 Certificate of Conformance: A written statement, signed by a qualified vendor representative certifying that the items or services defined herein comply with the specific requirements of the Purchase Order.

1.4.5 Certified Test Report: A written and signed document, approved by a qualified individual employed by the vendor that contains sufficient data and information to verify the actual properties of items and the actual results of all required tests.

1.4.6 Supplier Deviation Request (SDR): A document used to change drawings and specifications during fabrication. The person requesting the change provides a description of the change, documents affected, project number or this Engineering Specification Number to the project engineer for disposition. After approval, by the authorized JL Shepherd Project Engineer, the SDR becomes a design document.

1.4.7 Hold Point: A point in the fabrication/manufacturing sequence of operational steps when an inspection must be completed by an authorized JL Shepherd quality representative prior to work proceeding to the next operational step. Work may not proceed beyond the designated operational step without either an authorized JL Shepherd quality representative completing the inspection, or receipt of a written waiver from an authorized JL Shepherd quality representative.

1.4.8 Non-Conformance: A deficiency in characteristic, documentation, or procedure that renders the quality of an item unacceptable or indeterminate. Examples of non-conformance include: physical defects, test failures, incorrect or inadequate documentation, or deviation from prescribed processing, inspection or test procedures.

1.4.9 Progress Report: If applicable and as ordered, periodic statements of progress/updated schedule including status of major activities, milestones accomplished, variances and impact to overall schedule.

1.4.10 Qualified Vendor: A person or organization competent and recognized as knowledgeable to perform the specified functions.

1.4.11 Repair: The process of restoring a non-conforming characteristic to a condition such that the capability of an item to function reliably and safely is unimpaired, even though that item still does not conform to the original requirement.

1.4.12 Weld Repair Map: A listing of all repairs made by welding showing location, weld procedure, welder and NDE results.

1.4.13 Witness Point: A point in the fabrication/manufacturing sequence of operational steps when an authorized JL Shepherd quality representative must witness the performance of the design operational step. Work may not start on the designated operational step without either an authorized JL Shepherd quality representative being present or receipt of a written waiver from an authorized JL Shepherd Quality Assurance representative.

2.0 REFERENCES

If not otherwise noted, the most recent version of these referenced documents, codes and standards, at the date of issue of this Engineering Specification, shall be considered to be governing, and pre-empt any conflicting statements contained in documents presented by sub-contractors, if any.

2.1 ASME Section IX, "Welding and Brazing Qualifications"

2.2 ASME Section II, "Materials," and/or ASTM Material Standards

2.3 ASME Section III, Division I, Subsection NF, "Supports", Article NF-5000

2.4 ASME Section V, "Nondestructive Examination"

2.5 Steel Structures Painting Council, (SSPC)

2.6 ASNT-SNT-TC-1A-Nondestructive Testing, (NDT)

2.7 ASTM D-2856, Procedure B

2.8 ASTM D-2842 (Water absorption)

2.9 MDSC

2.10 ASTM D-2240 (Hardness, Shore Testing)

2.11 ASTM C-421 (Friability)

2.12 ASTM C-518 (Linear Thermal Expansion)

2.13 ASTM E-1269

2.14 ASTM D-240 (Heat and Combustion)

3.0 GENERAL REQUIREMENTS

3.1 Introduction and General Requirements

The polyurethane foam used within the impact limiters is comprised of a specific "formulation" of foam constituents (i.e., mix of chemical constituents) that defines the foam's physical characteristics such as density, compressive stress, and specific heat. Based on the foam's physical requirements, chemical constituents are combined into batches containing multiple parts (e.g., parts A and B) for easier handling. Therefore, a foam "batch" is defined as mixing into vats a specific foam formulation for each part. Based on the foam's physical requirements, portions from each batch part are combined to produce the liquid foam material for pouring into the component to be foamed. Thus, foam "pour" is defined as apportioning the batch parts into a desired quantity of liquid foam material for subsequent installation (pouring).

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The following sections describe the general requirements for chemical composition, constituent storage, foamed component preparation, foam material installation, and foam pour and test data records.

4.0 DESIGN AND/OR PERFORMANCE CRITERIA

Foam material physical characteristics for the below listed parameters shall be determined once for a particular foam formulation. If multiple components are to be foamed utilizing a specific foam formulation, then physical testing, as defined in paragraph 7.0 shall be performed.

Density: 12 pounds per cubic foot, ± 15%

Compressive Strength, Parallel to Rise at Strain: 1660 lbs/sq. in. @ 70% crush ± 15%.
Compressive Strength, Perpendicular to Rise: 1725 lbs/sq in @ 70% crush ± 15%.

Characteristics for Thermal Conductivity, Specific Heat, Leachable Chlorides, Flame Retardancy, and Intumescence are defined in Paragraph 7.0.

5.0 POLYURETHANE FOAM CHEMICAL COMPOSITION

The foam supplier shall certify that the chemical composition of the polyurethane foam is as delineated below, with the chemical component weight percents falling within the specified ranges. In addition, the foam supplier shall certify that the finished (cured) polyurethane foam does not contain halogen-type flame retardants or trichloromonofluoromethane (Freon 11).

Carbon	50% - 70%	Phosphorus	< 2%
Oxygen	14% - 34%	Silicon	< 1%
Nitrogen	4% - 12%	Chlorides	< 1%
Hydrogen	4% - 10%	Other	< 1%

5.1 Polyurethane Foam Constituent Storage

The foam supplier shall certify that the polyurethane foam constituents have been properly stored prior to use, and that the polyurethane foam constituents have been used within their shelf life.

5.2 Foamed Component Preparation

Prior to polyurethane foam installation, the foam supplier shall verify that an anti-bond agent, such as automotive wax, has been applied to the available component shell interior surfaces. In addition, due to the internal pressures generated during the foam pouring/curing process, the foam supplier shall visually verify that adequate bracing/shoring of the component shells is provided to maintain the dimensional configuration throughout the foam pouring/curing process.

6.0 POLYURETHANE FOAM INSTALLATION

6.1 Preparation

All surfaces shall be clean and free of contaminants. The direction of foam rise shall be vertically aligned with the impact limiter longitudinal axis. The surrounding walls of the component shell where the liquid foam material is to be installed shall be between 55 °F and 95 °F prior to foam installation. Measure and record the component shell temperature to an accuracy of ± 2 °F prior to foam installation. In the case of multiple pours into a single foamed component, the cured level of each pour shall be measured and recorded to an accuracy of ±1 inch.

6.2 Calculated vs. Actual Weight of Pour

Calculate and record the amount of materials required for "pour". Measure and record the weight of liquid foam material installed during each pour to an accuracy of ±10 pounds. All test samples shall be poured into disposable containers at the same time as the actual pour it represents, clearly marking the test sample container with the pour date and a unique pour identification number. All test samples shall be cut from a larger block to obtain freshly cut faces. Prior to physical testing, each test sample shall be cleaned of superfluous foam dust.

6.3 Polyurethane Foam Pour and Test Data Records

A production pour and testing record shall be compiled by the foam supplier during the foam pouring operation and subsequent physical testing. Upon completion of production and testing, the foam supplier shall issue certification referencing the production record data and test data pertaining to each foamed component. At a minimum, relevant pour and test data shall include:

- formulation, batch, and pour numbers, with foam material traceability, and pour date,
- foamed component description, part number, and serial number,
- instrumentation description, serial number, and calibration due date,
- pour and test data (e.g., date, temperature, dimensional, and/or weight measurements, compressive modulus, thermal conductivity, compressive stress, etc., as applicable), and
- technician and quality assurance/quality control (QA/QC) sign-off.

7.0 PHYSICAL CHARACTERISTICS DETERMINED FOR A FOAMED FORMULATION

The following subsections define the required physical characteristics of the polyurethane foam material used for the BU650B Impact Limiter designs. Testing for the various polyurethane foam physical characteristics is based on a "formulation", "batch", or "pour", as appropriate. The physical characteristics determined for a specific foam formulation are relatively insensitive to small variations in chemical constituents and/or environmental conditions, and therefore include physical testing for compressive modulus, Poisson's ratio, thermal expansion coefficient, thermal conductivity, specific heat, and leachable chlorides. Similarly, the physical characteristics determined for a batch are only slightly sensitive to small changes in formulation and/or environmental conditions during batch mixing, and therefore include physical testing for flame retardancy, intumescence, and leachable chlorides. Finally, the physical characteristics determined for a pour are also only slightly sensitive to small changes in formulation and slightly more sensitive to variations in environmental conditions during pour mixing, and therefore include physical testing for density and compressive stress.

7.1 Thermal Conductivity

A. The thermal conductivity test shall be performed using a Heat Flow Meter (HFM) apparatus. The HFM establishes steady state unidirectional heat flux through a test specimen between two parallel plates at constant but different temperatures. By measurement of the plate temperatures and plate separation, Fourier's law of heat conduction is used by the HFM to automatically calculate thermal conductivity. Description of a typical HFM is provided in ASTM C518[6]. The HFM shall be calibrated against a traceable reference specimen per the HFM manufacturer's operating instructions.

B. Three (3) test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the HFM manufacturer's operating instructions.

C. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.

D. Measure and record the necessary test sample parameters as input data to the HFM per the HFM manufacturer's operating instructions.

E. Perform thermal conductivity testing and record the measured thermal conductivity for each test sample following the HFM manufacturer's operating instructions.

F. Determine and record the average thermal conductivity of the three test samples. The numerically averaged thermal conductivity of the three test samples shall nominally be 0.24 Btu-in/hr-ft^2-°F ±20% (i.e., within the range of 0.21 to 0.31 Btu-in/hr-ft^2-°F) for 11½ pcf density foam.

7.2 Specific Heat Test

A. The specific heat test shall be performed using a Differential Scanning Calorimeter (DSC) apparatus. The DSC establishes a constant heating rate and measures the differential heat flow into both a test specimen and a reference specimen. Description of a typical DSC is provided in ASTM E1269[7]. The DSC shall be calibrated against a traceable reference specimen per the DSC manufacturer's operating instructions.

B. Three (3) test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the DSC manufacturer's operating instructions.

C. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.

D. Measure and record the necessary test sample parameters as input data to the DSC per the DSC manufacturer's operating instructions.

E. Perform specific heat testing and record the measured specific heat for one test sample following the DSC manufacturer's operating instructions.

F. Determine and record the average specific heat of one test specimen. The numerically averaged specific heat at 75 °F of the test sample shall be 0.35 Btu/lb$_m$-°F ±20% (i.e., within the range of 0.28 to 0.42 Btu/lb$_m$-°F).

7.3 Leachable Chlorides

A. The leachable chlorides test shall be performed using an ion chromatograph (IC) apparatus. The IC measures inorganic anions of interest (i.e., chlorides) in water. Description of a typical IC is provided in EPA Method 300.0[8]. The IC shall be calibrated against a traceable reference specimen per the IC manufacturer's operating instructions.

B. One (1) test sample shall be taken from a pour from each foam batch. The test sample shall be a cube with dimensions of 2.00 ±0.03 inches.

C. Place the test sample in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test sample. Measure and record the room temperature to an accuracy of ±2 °F.

D. Obtain a minimum of 550 ml of distilled or de-ionized water for testing. The test water shall be from a single source to ensure consistent anionic properties for testing control.

E. Obtain a 400 ml, or larger, contaminant free container that is capable of being sealed. Fill the container with 262 ±3 ml of test water. Fully immerse the test sample inside the container for a duration of 72 ±3 hours. If necessary, use an inert standoff to ensure the test sample is completely immersed for the full test duration. Seal the container.

F. Obtain a second, identical container to use as a "control". Fill the control container with 262 ±3 ml of the same test water. Seal the control container.

G. At the end of the test period, measure and record the leachable chlorides in the test water per the IC manufacturer's operating instructions. The leachable chlorides in the test water shall not exceed one part per million (1 ppm).

7.4 Flame Retardancy

A. Three (3) test samples shall be taken from a pour from each foam batch. Each test sample shall be a rectangular prism with nominal dimensions of 0.5 inches thick, 3.0 inches wide, and a minimum length of 8.0 inches.

B. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.

C. Install a □3/8 inches, or larger, Bunsen or Tirrill burner inside an enclosure of sufficient size to perform flame retardancy testing. Adjust the burner flame height to 1½ ±1/8 inches. Verify that the burner flame temperature is 1,550 °F, minimum.

D. Support the test sample with the long axis oriented vertically within the enclosure such that the test sample's bottom edge will be 3/4 ±1/16 inches above the top edge of the burner.

E. Move the burner flame under the test sample for an elapsed time of 60 ±2 seconds. As illustrated, align the burner flame with the front edge of the test sample thickness and the center of the test sample width.

F. Immediately after removal of the test sample from the burner flame, measure and record the following data:

1. Measure and record, to the nearest second, the elapsed time until flames from the test sample extinguish.

2. Measure and record, to the nearest second, the elapsed time until drips from the test sample extinguish.

3. Measure and record, to the nearest second, the burn length following cessation of all visible burning and smoking.

G. Flame retardancy testing acceptance is based on the following criteria:

1. The numerically averaged flame extinguishment time of each of the three test samples shall not exceed fifteen (15) seconds.
2. The numerically averaged flame extinguishment time of drips from each of the three test samples shall not exceed three (3) seconds.
3. The numerically averaged burn length of each of the three test samples shall not exceed six (6) inches.

7.5 Intumescence

A. Three (3) test samples shall be taken from a pour from each foam batch. Each test sample shall be a cube with nominal dimensions of 2.0 inches.

B. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.

C. Preheat a furnace to 1,475 °F ±18 °F.

D. Identify two opposite faces on each test sample as the thickness direction. Measure and record the initial thickness (ti) of each test sample to an accuracy of ±0.01 inches.

E. Mount a test sample onto a fire resistant fiberboard, with one face of the thickness direction contacting to the board. The direction of foam rise shall be normal to the fiberboard face. The test samples may be mounted by installing onto a 12 to 16 gauge wire (Ø0.105 to Ø0.063 inches, respectively) of sufficient length, oriented perpendicular to the fiberboard face. The test samples may be pre-drilled with an undersized hole to allow installation onto the wire.

F. Locate the test sample/fiberboard assembly over the opening of the pre-heated furnace for a 90 ±3 second duration. After removal of the test sample/fiberboard assembly from the furnace, gently extinguish any remaining flames and allow the test sample to cool.

G. Remove the test sample from the fiberboard. Measure and record the final thickness (tf) of the test sample to an accuracy of ±0.1 inches.

H. For each sample tested, determine and record the intumescence, "I", as a percentage of the original sample length as follows: $I = ((t_f - t_i) \div t_i) \times 100$.

I. Determine and record the average intumescence of the three test samples. The numerically averaged intumescence of the three test samples shall be a minimum of 50%.

7.6 Density

A. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0 inch thick (T), minimum, × 2.0 inches wide (W) × 2.0 inches long (L).

B. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.

C. Measure and record the weight of each test sample to an accuracy of ±0.01 grams.

D. Measure and record the thickness, width, and length of each test sample to an accuracy of ± 0.001 inches.

E. Determine and record the room temperature density of each test sample utilizing the following formula:

$$P_{\text{foam}} = \frac{\text{Weight, g}}{453.6\ \text{g/lb}} \times \frac{1728\ \text{in}^3/\text{ft}^3}{T \times W \times L\ \text{in}^3}\ \text{,pcf}$$

F. Determine and record the average density of the three test samples. The numerically averaged density of the three test samples shall nominally be within ±15% (i.e., within the range of 10.2 to 13.8 pcf for nominal 12 pcf foam).

7.7 Parallel-to-Rise Compressive Stress

A. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0 inch thick (T), minimum, × 2.0 inches wide (W) × 2.0 inches long (L).

B. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.

C. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.001 inches.

D. Compute and record the surface area of each test sample by multiplying with width by the length (W x L = Area).

E. Place a test sample in a Universal Testing Machine. Lower the machine's crosshead until it touches the test sample. Set the machine's parameters for the thickness of the test sample.

F. Apply a compressive load to each test sample at a rate of 0.10 ±0.05 inches/minute until a strain of 70%, or greater, is achieved. For each test sample, plot the compressive stress versus strain and record the compressive stress at strains of 10%, 40%, and 70%.

G. Determine and record the average parallel-to-rise compressive stress of the three test samples from each pour. The average parallel-to-rise compressive stress for each pour shall be the nominal compressive stress ±20% at strains of 10%, 40%, and 70%.

H. Determine and record the average parallel-to-rise compressive stress of all test samples from each foamed component. The average parallel-to-rise compressive stress for a foamed component shall be 500 psi (± 20%), 570 psi (± 15%), and 1600 psi (± 15%) at strains of 10%, 40%, and 70%, respectively.

7.8 Perpendicular-to-Rise Compressive Stress

A. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0 inch thick (T) × 2.0 inches wide (W) × 2.0 inches long (L). The thickness dimension shall be the perpendicular-to-rise direction.

B. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.

C. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.001 inches.

D. Compute and record the surface area of each test sample by multiplying the width by the length (i.e., W × L).

E. Place a test sample in a Universal Testing Machine. Lower the machine's crosshead until it touches the test sample. Set the machine's parameters for the thickness of the test sample.

F. Apply a compressive load to each test sample at a rate of 0.10 ±0.05 inches/minute until a strain of 70%, or greater, is achieved. For each test sample, plot the compressive stress versus strain and record the compressive stress at strains of 10%, 40%, and 70%.

G. Determine and record the average perpendicular-to-rise compressive stress of the three test samples from each pour. The average perpendicular-to-rise compressive stress for each pour shall be 500 psi, 560 psi, and 1585 psi at strains of 10%, 40%, and 70%, respectively*.

H. Determine and record the average perpendicular-to-rise compressive stress of all test samples from each foamed component. The average perpendicular-to-rise compressive stress for each pour shall be 500 psi, 560 psi, and 1585 psi at strains of 10%, 40%, and 70%, respectively*.

*NOTE: The average compressive stress at 10% strain for a foam component may be ± 20%, provided the average compressive stress @ 40% and 70% strain for each pour is ± 15%.

7.9 Shielding Tests

The BU650B Impact Limiter is not intended to act as biological shielding. No tests are required.

8.0 CLOSURE OF "POUR" HOLES AND VENTS

8.1 The 1/8" diameter ventilation holes are to be closed with threaded allen-type insert.

8.2 The "pour" holes, approximately 3" in diameter should be closed by welded cover, having an approximate 1" diameter threaded hole in the center. The hold should be filled with a soft plastic plug or paraffin wax seal in order to serve as a pressure relief during thermal expansion of the foam.

9.0 PACKAGING AND SHIPPING

9.1 The JL Shepherd Quality Assurance Representative or designee shall review and approve the Quality Assurance data package prior to final acceptance.

10.0 STATEMENT OF CHANGES / REVISIONS

10.1 Date of Revision: June 7, 2012

10.2 Revision Number: 3

10.3 Pages and items revised:

Cover Page: Changed Revision number and date, corrected cask model number, corrected titles of responsible individuals.
Page 3: Corrected cask model number, Removed "Manager, Quality Assurance" under authorized JL Shepherd representatives and added, "BU650B".
Page 4: Added ( ) around "SDR" in 1.4.6.
Page 5: Deleted "MFFP" in section 3.1, first line and deleted the "a" after Thus in the next to the last line.
Page 6: In section 4.0, 2nd sentence, changed "form" to "foam".
Page 7: Last dot under section 6.3, made letters small in "Quality Assurance/Quality Control" to be consistent with the beginning of the dot.
Page 8: Corrected cask model number.
Page 14: Corrected cask model number.