71-9315

BWXT Y-12

Protecting America's Future

August 15, 2005

CCN-014590

Mr. Shawn Williams
U.S. Nuclear Regulatory Commission
Mail Stop: O13D13
Washington, D.C. 20555-0001

Responses to RAI-1, on the ES-3100 Type-B Shipping Container
Docket No. 71-9315, TAC No. L23818

Attached are the BWXT Y-12 responses to the Requests for Additional Information (RAI) for the ES-3100 Type B shipping container. The responses are compiled into the attached document, Y/LF-747. Included with the response document are change pages to the ES-3100 license application, specifically, *Safety Analysis Report, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents*, Y/LF-717, Rev. 0. The Safety Analysis Report (SAR) change pages reflect the incorporation of specific wording modifications as described in the RAI responses.

RAI-1 for the ES-3100 application was received by the U.S. Department of Energy (DOE) on June 30, 2005. Subsequent to this receipt, the RAIs were reviewed by the ES-3100 Project Team and two conference calls were conducted with NRC personnel for clarification. The conference calls resulted in a thorough understanding of the NRC requests and a proposed path forward for resolution.

In addition to the attached response document and SAR change pages, a DVD has been provided containing the following information:

- Analyses that support the response to RAI 2-19 as referenced in Y/LF-747.
- A reference document that supports the response to RAI 2-17 as referenced in Y/LF-747.

The response to RAI 2-8 references a Sandia document entitled, *Tiedown Procedures for Type-B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*. This document supports all packages that are shipped by DOE in SSTs and SGTs, as will be the case with the ES-3100. An entry for the ES-3100 in the tie-down procedures is forthcoming, but a similar package (DOT 6M) can be shown as an example and, for that package, no structural elements are

NMSS01

used for tie-down purposes. The tie-down procedure document has been classified as Official Use Only (OUO) by DOE, and therefore, is not attached to this submittal. Please advise if a copy is needed for the review process, and how the OUO document should be transmitted.

The attached change pages should be incorporated into your copies of the ES-3100 SAR. If you have any questions regarding this submittal, please contact me at (865) 576-8254.

Very truly yours,

Jeffrey G. Arbital
BWXT Y-12 Container Program Manager

JGA:slc

Attachments: As stated

cc: B. G. Eddy, NNSA YSO
R. M. George, DOE, NA-261
A. Janasi, Knolls Atomic Power Laboratory
R. Koenig, WSRC
P. T. Mann, DOE, NA-124
T. D. Pflaum, DOE, NA-131
J. W. Pugh, Nuclear Fuel Services, Inc.
E. D. Ragos, NNSA YSO
J. M. Shuler, DOE, EM-24
S. A. Thompson, DOE, NA-15
D. R. Tousley, DOE, NA-261
S. A. Williams, U.S. Nuclear Regulatory Commission (10)
S. J. Williams, BWXT Lynchburg

ES-3100 Safety Analysis Report

Page changes # 1

Response to RAI # 1
Docket No. 71-9315
TAC No. L23818

August 15, 2005

(please replace the following pages in Y/LF-717, Rev. 0, February 25, 2005)

SAFETY ANALYSIS REPORT, Y-12 NATIONAL SECURITY COMPLEX, MODEL ES-3100 PACKAGE WITH BULK HEU CONTENTS

Prepared by the
Oak Ridge Y-12 National Security Complex
Oak Ridge, Tennessee 37831
Managed by
BWXT Y-12 L.L.C.
for the
U. S. Department of Energy
under contract DE-AC05-84OR21400

August 15, 2005

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

The following contractors, consultants, and companies assisted BWXT Y-12, L.L.C., in the preparation of this Safety Analysis Report:

G2 Engineering and Management, Inc.
Navarro Research & Engineering, Inc.
UT-Battelle

CONTENTS

CONTENTS continued

REVISION LOG

Date	Revision No.	Description	Pages
02/25/05	0	Original issue	All
08/15/05	Page Change 1	Page changes resulting from *Responses to Request for Additional Information* #1, Y/LF-747.	title page, iv, xxiii, 1-4, 1-145, 2-2, 2-3, 2-6, 2-31, 2-32, 2-33, 2-34, 2-57, 2-59, 2-61, 2-107, 2-125, 2-131, 2-171, 2-173, 2-181, 2-183, 2-185, 2-186, 2-189, 2-367, 2-458, 2-675, 8-8, 8-9, 8-31

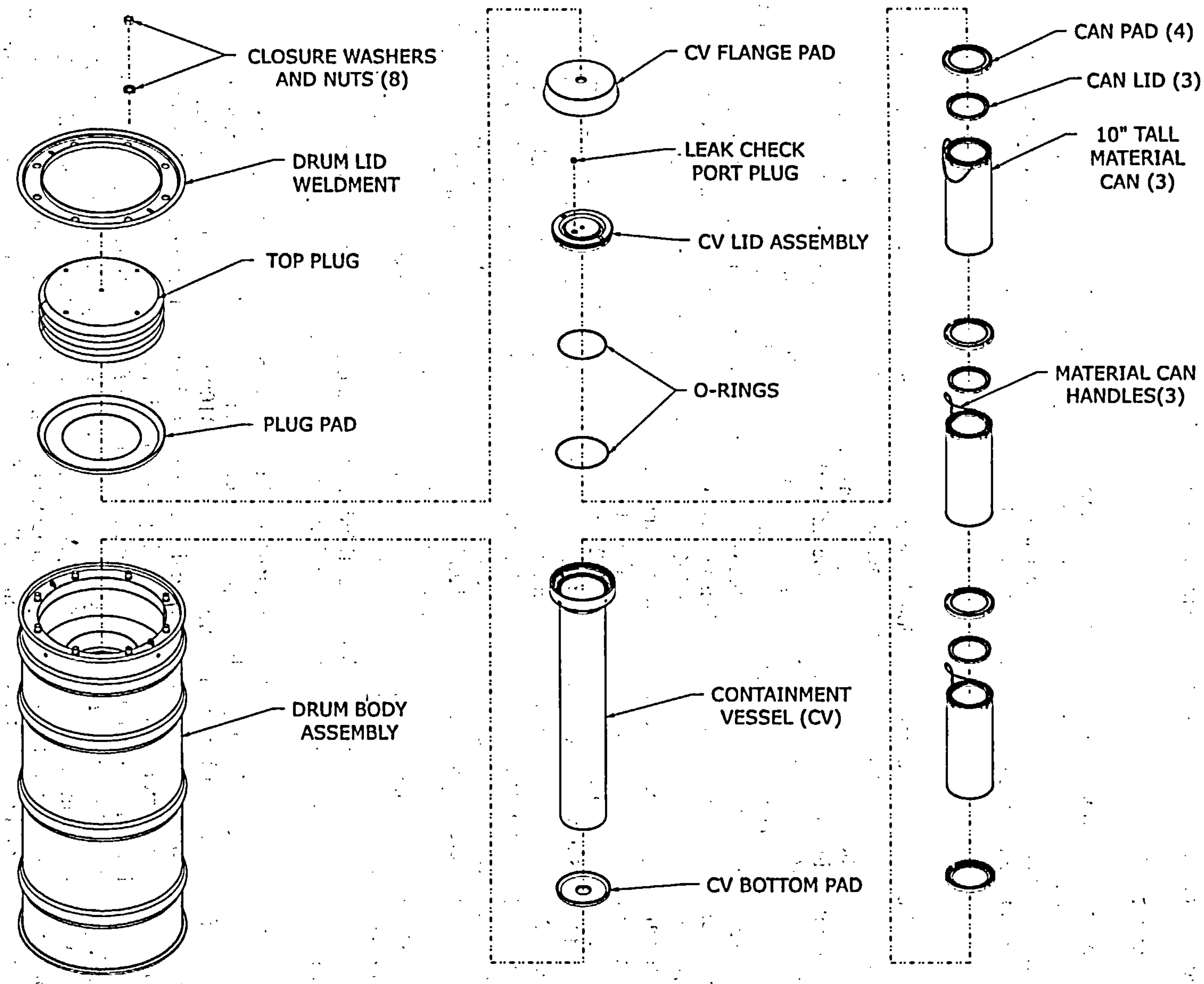

Fig. 1.2. Exploded view of the ES-3100 package with bulk HEU contents.

The authorized maximum gross weight of the ES-3100 package is 190.5 kg (420 lb). The ES-3100 packaging as specified in this SAR is classified as a Category II package (see Appendix 1.4.6). However, since the ES-3100 shipping package may be used for future contents having higher A_2 values, the package has been designed and analyzed to meet the requirements of a Category I package.

1.2.1 Packaging

The main functions of the packaging are containment, shielding, and nuclear criticality safety. The bulk HEU contents create a maximum decay heat of approximately 0.4 W (Sect. 1.2.3.7 and Sect. 3.1.2); therefore, the packaging does not require any special design features such as coolant valves or continuous venting to meet the thermal requirements of 10 CFR 71.

1.2.1.1 Drum Assembly

The drum assembly consists of a double open-head reinforced stainless-steel 30-gal drum, arched cover that forms the bottom, arched lid, inner liner, and top plug with cast refractory insulation (Kaolite) [see Drawing M2E801580A001, Appendix 1.4.1]. The inside diameter of the drum is 46.36 cm (18.25 in.) with an overall height of 110.49 cm (43.5 in.) including the cover and lid (Drawings M2E801580A004 and M2E801580A001, Appendix 1.4.1). The outside diameter of the drum (including the chimes) is 49.2 cm (19.37 in.). The drum and lid are made from 16-gauge [~0.152-cm (0.0598-in.)-thick] type 304 or 304L stainless steel. A 12-gauge [~0.267-cm (0.105-in.)-thick] stainless-steel arched cover (Drawing M2E801580A005, Appendix 1.4.1) is welded to the double open-head drum to create the bottom of the drum assembly. An inner liner (Drawing M2E801580A003, Appendix 1.4.1) is attached to the drum by an internal flange (angle) that is welded to both the drum and liner. The cavity created by the inner liner for placement of a containment vessel is a three-tier volume. The uppermost tier accommodates the top plug and has an inside diameter of 37.52 cm (14.77 in.) and is 13.26 cm (5.22 in.) deep (Drawing M2E801580A003, Appendix 1.4.1). The second tier, which accommodates the containment vessel flange, has a 21.84-cm (8.60-in.) inside diameter that is 5.59 cm (2.20 in.) deep (Drawing M2E801580A003, Appendix 1.4.1). The third tier, which accommodates the containment vessel body, has a 15.85-cm (6.24-in.) inside diameter that is 78.31 cm (30.83 in.) deep (Drawing M2E801580A003, Appendix 1.4.1). An additional cavity is created between the second and third tier liners. This cavity runs the full length of the third tier height [78.31 cm (30.83 in.)] and is approximately 5.99 cm (2.36 in.) thick (Drawing M2E801580A003, Appendix 1.4.1). This cavity is filled with a castable refractory [Thermo Electron Corporation Catalog No. 277-4 (Cat 277-4)] for neutron attenuation purposes. The additional cavities between the liner and the drum are filled with an inorganic castable refractory material (Kaolite 1600), which acts as both an impact-absorbing and thermal-insulating material.

In accordance with NUREG/CR-3854, Part 4.3 for a Category I shipping package, an acceptable specification for drums used in any of the component safety groups is U.S. Department of Transportation (DOT) Specification 17C or better. The drum used in the ES-3100 is fabricated in accordance with the dimensional requirements of MIL-D-6054F and modified as shown on Drawing M2E801580A004 (Appendix 1.4.1). Material, fabrication, and quality control criteria are generally equivalent to those imposed for a DOT Specification 17C drum. Furthermore, the drum of the ES-3100 is part of a performance-based package that has been tested and analyzed to demonstrate its ability to maintain confinement and containment of its contents under both NCT and HAC. By certifying that the outer shell of the Drum Assembly used in production meets the same specifications as those tested and analyzed, as described in subsequent sections of this SAR, the outer drum shell used for the ES-3100 is acceptable for a Category 1 shipping package.

As previously discussed, the drum has been modified by the attachment of an inner liner connected to the drum by an internal flange welded to both the drum and the liner. Weld studs are attached to the upper

PACKAGE CATEGORY DETERMINATION

The ES-3100 with HEU content package has a maximum activity of 0.3112 Tbq (8.41 Ci) at 10 y after initial fabrication; the maximum number of A_2s carried is 290.26 at 50 y after initial fabrication (Table 4.4). Based on the guidance from 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)*, this package is classified in Table 1.1 of NUREG-1609 as a Category II package.

2. STRUCTURAL EVALUATION

The ES-3100 package is used to ship bulk highly enriched uranium (HEU). Content will be packed in various size convenience cans made of stainless or tin-plated carbon steel. The cans shall have a diameter of ≤12.7 cm (5 in.) and heights of ≤25.4 cm (10 in.). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers when required) does not exceed the inside working height of the containment vessel. Any closure on the convenience can is allowed. Polyethylene bags may be used inside or outside any convenience can as long as the loading restrictions in Sect. 1.2.3.8 are met. The amount of polyethylene bagging used inside the ES-3100 containment vessel is limited to 500 g. In addition, polyethylene bags or other packing materials that offgas at temperatures above ambient may not be used inside the containment vessel if convenience cans with diameters exceeding 4.25 in. are used. The maximum payload inside the containment vessel will be as follows and as shown in Table 2.1: (1) 24 kg oxide or compounds (up to 100% enrichment in ^{235}U); (2) HEU oxide shall be in the form of UO_2, UO_3, or U_3O_8; (3) 24 kg of uranyl nitrate crystals; (4) 36 kg of uranium metal and alloy (up to 100% enrichment in ^{235}U); (5) HEU metal and alloy may be in the form of broken pieces, ingots, buttons, small castings or fuel; and (6) the maximum weight of all contents, including nuclear material, convenience cans, polyethylene bags, spacers, etc., shall not exceed 40.82 kg (90 lb). Uranium and transuranic isotopic allowances are defined in Sect. 4. Mass limits and total weights for each shipping arrangement are defined and described in Sect. 2.1.3. The 40.82-kg (90-lb) maximum containment vessel content weight and 36-kg (79.37-lb) HEU content weight limits have been established as a bounding case for the maximum structural, thermal, and containment limit for the shipping package. The lowest possible mass of 2.77 kg (6.11 lb) HEU has been established as the lower bounding case for structural, thermal, and containment limits for the shipping package. The above content masses and forms used for the proposed content do not take into consideration limits based on shielding and subcriticality.

As described in the following sections, design analysis, similarity, drop simulations, and the full-scale testing documented herein demonstrates that the ES-3100 package is in compliance with the requirements of Title 10 Code of Federal Regulations (CFR) 71 and Title 49 CFR 100–178 when it is used to ship contents described above. The maximum bounding activity of the contents (36 kg of HEU) is 3.1039×10^{-1} TBq (8.39 Ci) when the maximum activity-to-A_2 value is reached at ~50 years from material fabrication. The corresponding maximum number of A_2s carried is 290.26. This information is further discussed in Sect. 4.

Table 2.1. Proposed HEU contents for shipment in the ES-3100

Form	Chemical or physical description	Total weight of HEU contents kg (lb)
HEU oxide	UO_2, UO_3, U_3O_8	24 (52.91)
Uranyl nitrate crystals	$UO_2(NO_3)_2 + 6H_2O$	24 (52.91)
HEU metal and alloy	Specific geometric shapes (spheres, cylinders, square bars or slugs) or broken metal pieces	36 (79.37)

2.1 DESCRIPTION OF STRUCTURAL DESIGN

2.1.1 Discussion

The principal structural members of the shipping package consist of the following: the drum assembly, the containment boundary, packaging material, and the contents. Each of these will be described and discussed in the following sections.

2.1.1.1 Drum assembly

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact and thermal barrier surrounding the containment boundary. Preserving the location of the containment boundary within the packaging prevents reduction of the shielding and subcriticality effectiveness. The drum assembly for the ES-3100 consists of an internally flanged Type 304L stainless-steel 30-gal modified drum with two type 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter (Kaolite) and one filled with noncombustible cast neutron absorber (Cat 277-4), a stainless-steel top plug with cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A031, Appendix 1.4.1). The nominal weight of these components is 131.89 kg (290.76 lb).

The drum's diameters (inner diameter of 18.25 in.) and corrugations meet the requirements of Military Standard MS27683-7. All other dimensions are controlled by Drawing M2E801580A004 (Appendix 1.4.1). Modifications to the drum from MS27683-7 include the following: (1) the overall height was increased; (2) the drum was fabricated with two false wire open ends; and (3) a 0.27-cm (12-gauge, 0.1046-in.)–thick concave cover was welded to the bottom false wire opening (Drawing M2E801580A005, Appendix 1.4.1). Four 0.795-cm (0.313-in.)–diameter equally spaced holes are drilled in the top external sidewall to prevent a pressure buildup between the drum and inner liner. The holes are sealed with a plastic plug to provide a moisture barrier for the cast refractory insulation during Normal Conditions of Transport (NCT). The cavity created by the inner liners is a three-tiered volume with a 37.52-cm (14.77-in.) inside diameter 13.26 cm (5.22 in.) deep, a 21.84-cm (8.60-in.) inside diameter 5.59 cm (2.20 in) deep, and an additional 15.85-cm (6.24-in.) inside diameter 78.31-cm (30.83 in.) deep. The volume between the mid liner and the drum and the top plug's internal volume is completely filled with the noncombustible cast refractory insulation called Kaolite 1600 from Thermal Ceramics, Inc. Kaolite properties, such as mechanical, thermal conductivity, and impact, are presented in Appendix 2.10.3. The volume between the most inward liner and the mid liner wall is completely filled with a noncombustible neutron absorber (poison) from Thermo Electronic Corp. called Cat 277-4. Cat 277-4 properties, such as thermophysical, mechanical, and neutron activation, are presented in Appendix 2.10.4. BoroBond4, another noncombustible neutron absorber, was used only in prototype test packages instead of Cat 277-4. The drum body, inner liners, and lid are fabricated from 0.15-cm (16-gauge, 0.0598-in.) thick Type 304/304L stainless-steel sheet. A rolled stainless-steel flange with a 5.08 × 5.08 × 0.64-cm (2 × 2 × 0.25-in.) thick modified stainless-steel structural angle is welded around the top of the mid inner liner. The mid inner liner is then welded to the inside surface of the drum along this flange. Eight ⅝-11-UNC-2A studs welded to the drum and silicon bronze nuts provide the structural attachment for the drum lid, and are torqued to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) at assembly. The drum lid's diameter and shape meet the requirements of Military Standard MS27683-61. All other dimensions are controlled by Drawings M2E801580A006 and A007, Appendix 1.4.1. The welded angle ring (Find Number 3 on Drawing M2E801580A006, Appendix 1.4.1) provides the lid an inner flange. The welded angle ring was incorporated in the ES-3100 package for use during handling and transport to protect the lid closure studs and nuts. During transport, the welded angle ring helps position drum tie-down adapters that are used for tie-down of a single unit configuration in Safe-Secure Trailers/Safeguards Transporters

(SSTs/SGTs) in accordance with U.S. Department of Energy (DOE) Order 5610.14. The drum is marked by two stainless-steel data plates. The data plate lettering and mounting requirements on the drum are shown on Drawings M2E801580A010 and M2E801508A031 (Appendix 1.4.1), respectively. Painting and marking requirements for the drum are shown on Drawing M2E801508A001 (Appendix 1.4.1). Two lugs are welded to the mid inner liner and project through the drum lid at assembly. Each lug has a 0.953-cm (0.38-in.)–diameter hole through which a tamper-indicating device (TID) can be threaded.

The volume between the drum and mid-liner is filled with a lightweight noncombustible cast refractory material called Kaolite 1600. The top plug is also filled with this material and represents the thermal insulation and impact limiting barrier. The material is composed of portland cement, water, and vermiculite and has an average density of 358.8 kg/m^3 (22.4 lb/ft^3). The procedure for manufacturing and documenting the installation of this material, JS-YMN3-801580-A003 (Appendix 1.4.4), is referenced on Drawings M2E801580A002 and M2E801580A008 (Appendix 1.4.1) for the drum assembly weldment and top plug weldment, respectively. The insulation has a maximum continuous service temperature limit of 871°C (1600°F) due to the presence of the vermiculite and portland cement.

The volume between the most internal liner and the mid-liner is filled with a noncombustible cast neutron absorber (poison) material from Thermo Electronic Corp. called Cat 277-4. The material is a high alumina borated concrete composed of aluminum, magnesium, calcium, boron, carbon, silicon, sulfur, sodium, iron and water. The final mixture has an average density of 1681.9 kg/m^3 (105 lb/ft^3). The procedure for manufacturing and documenting the installation of this material, JS-YMN3-801580-A005 (Appendix 1.4.5), is referenced on Drawing M2E801580A002 (Appendix 1.4.1). This neutron absorber material has a maximum continuous service temperature limit of 150°C (302°F) in order to retain the bound mass of water in the final cured mixture for subcriticality control.

The top plug is fabricated in accordance with Drawing M2E801580A008 with an overall diameter of 36.50 cm (14.37 in.) and a height of 13.41 cm (5.28 in.). The plug's rim, bottom sheet, and top sheet are fabricated from 0.15-cm (16-gauge, 0.0598-in.) thick Type 304/304L stainless-steel sheet per ASME SA240. Four lifting inserts are welded into the top sheet for loading and unloading operations. The internal volume of the top plug is filled with Kaolite 1600 in accordance with JS-YMN3-801580-A003, Appendix 1.4.4.

Three silicone rubber pads complete the drum assembly. One pad is placed on the bottom of the most internal liner to support the containment vessel during transport. Another pad is placed on the top shelf of the mid-liner to support the top plug during transport. The final plug is placed over the top of the containment vessel during transport. The pads are molded to the shapes as defined on Drawing M2E801580A009 (Appendix 1.4.1). The material is silicone rubber with a Shore A durometer reading of 22 ±5.

2.1.1.2 Containment boundary

The containment vessel's body, lid assembly, and inner O-ring provide the containment boundary (Fig. 1.3). Two methods of fabrication may be used to fabricate the containment vessel body of the ES-3100 package as shown on Drawing M2E801580A012 (Appendix 1.4.1). The first method uses a standard 5-in., schedule 40 stainless-steel pipe per ASME SA-312 Type TP304L, a machined flat-head bottom forging per ASME SA-182 Type F304L, and a machined top flange forging per ASME SA-182 Type F304L. The nominal outside diameter of the 5-in schedule 40 pipe is machined to match the nominal wall thickness of 0.100 in. Each of these pieces is joined with circumferential welds as shown on sheet 2 of Drawing M2E801580A012 (Appendix 1.4.1). The top flange is machined to match the schedule 5-in. pipe, to provide two concentric half-dove tailed O-ring grooves in the flat face, to provide locations for two 18-8 stainless-steel dowel pins, and to provide the threaded portion for closure using the lid assembly. The second method of fabrication uses forging, flow forming, or metal spinning to create the complete body (flat bottom,

cylindrical body, and flange) from a single forged billet or bar with final material properties in accordance with ASME SA-182 Type F304L. The top flange area using this fabrication technique is machined identically to that of the welded forging method. The lid assembly, which completes the containment boundary structure, consists of a sealing lid, closure nut, and external retaining ring (Drawing M2E801580A014, Appendix 1.4.1). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.4.1) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut (Drawing M2E801580A016, Appendix 1.4.1) is machined from a Nitronic 60 stainless-steel bar with material properties in accordance with ASME SA-479. These two components are held together using a WSM-400-S02 external retaining ring made from Type 302 stainless steel. The sealing lid is further machined to accept a ⅝-16 swivel hoist ring bolt to facilitate loading and unloading, to provide a leak-check port between the elastomeric O-rings, and notched along the perimeter to engage two dowel pins. The lid assembly, with the O-rings in place on the body, are joined together by torquing the closure nut and sealing lid assembly to 162.70 ± 6.78 N·m (120 ± 5 ft-lb). The sealing lid portion of the assembly is restrained from rotating during this torquing operation by the two dowel pins installed in the body flange. An evacuation port is located between the O-rings in the containment vessel to facilitate a pressure rise or drop leakage test following assembly or 10 CFR 71 compliance testing. This port is sealed during transport using a modified VCO threaded plug. Only the inner O-ring is considered a part of the containment boundary.

There are no penetrations of, connections to, or fittings for the sealed containment boundary. To meet the requirements for package certification, the containment boundary must remain intact during all conditions of transport. This integrity must be demonstrated by test or other acceptable methodology for NCT and Hypothetical Accident Conditions (HAC) as described in 10 CFR 71.

2.1.1.3 Packaging Materials

Contents will be packed in various size convenience cans made of stainless or tinned carbon steel. The cans shall have a diameter of ≤12.7 cm (5 in.) and heights of ≤25.4 cm (10 in.). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers and pads as required) does not exceed the inside working height of the containment vessel (31 in.). Any closure on the convenience can is allowed. Polyethylene bags may be used inside or outside any convenience can that has a diameter of ≤10.8 cm (4.25 in.). In some packing arrangements, silicone rubber pads will be used between convenience cans. Also some arrangements will require spacers between cans. These spacers are thin stainless-steel cans filled with the noncombustible cast neutron poison. Each convenience can and spacer is equipped with a stainless-steel band clamp and nylon coated wire for loading and unloading operations. The spacers are ~10.11 cm (3.98-in.) in diameter by 3.12 cm (1.23 in.) in height and weigh ~0.47 kg (1.03 lb). In order to minimize displacement of convenience cans during transport, stainless-steel scrubbers may be added on top of the last can in the containment vessel. If partial loading configurations are employed and empty cans are used, these empty cans will be loaded last and will require a minimum 0.32 cm (⅛ in.) diameter hole to be placed through the lid.

2.1.2 Design Criteria

2.1.2.1 General standards for all packages

The general design standards for all packages in accordance with 10 CFR 71.41(a) through (e), (g) and (h) are addressed in the following paragraphs.

10 CFR 71.43(a)

Requirement: The smallest overall dimension of a package shall not be <10 cm (4 in.).

Compliance: The drums' outside diameter over the rolled rings is 49.20 cm (19.37 in.), and the outside height including the lid is 110.49 cm (43.50 in.). The minimum outside diameter of the ES-3100 containment vessel is 13.36 cm (5.26 in.), and the overall height is 82.30 cm (32.40 in.). Therefore, the packaging meets this requirement.

10 CFR 71.43(b)

Requirement: The outside of the package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evidence that the package has not been opened by unauthorized persons.

Compliance: The removable drum head is attached to the body by eight ⅝-11-UNC-2B silicon bronze nuts and ⅝-in. nominal washers. Two 0.51-cm (0.20-in.)-thick lugs with 0.953-cm (0.38-in.)-diam holes (Drawing M2E801580A005, Appendix 1.4.1) project through slots in the drum lid and provide attachment for tamper-indicating devices (TIDs). These TIDs consist of a stainless-steel cable with an aluminum crimp closure or equivalent. The requirement is satisfied by the TIDs, which are installed as specified in Sect. 7.1.2.2. The TID is only required when the containment vessel has HEU in the package. It is not required for empty shipments.

10 CFR 71.43(c)

Requirement: Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package.

Compliance: The fastened lid on the drum with tamper-indicating features provides assurance that the drum assembly will not be unintentionally breached. The containment boundary is sealed using the lid assembly and closure nut (Appendix 1.4.1) to ensure that this boundary will be breached only through a deliberate effort, and then only after the drum assembly is breached. The design of the containment boundary is analyzed in Appendix 2.10.1 for a differential pressure of 699.82 kPa (101.5 psi) internal and 150 kPa (21.7 psi) external. The internal design pressure exceeds the maximum differential pressure of 97.63 kPa (14.16 psi) and 206.05 kPa (29.89 psi) attained during NCT (Sect. 3.4.2) and HAC (Sect. 3.5.3), respectively. In addition, calculation results are provided in Sects. 2.6.1 and 2.7.4.3 to demonstrate that the stresses in the containment boundary and closure nut threads do not exceed the stress limits established by the ASME code for NCT and HAC. Therefore, the containment boundary will not be breached during any mode of transport due to pressurization of the containment boundary.

10 CFR 71.43(d)

Requirements: A package must be made of materials and construction that assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents including possible reaction resulting from inleakage of water, to the maximum credible extent. Account must be taken of the behavior of materials under irradiation.

Compliance: Compliance with the regulatory requirements are discussed in Sect. 2.2.2.

10 CFR 71.43(e)

Requirement: A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage.

Compliance: No penetrations, connections, or fittings into the containment vessels exist; therefore, the requirements of 10 CFR 71.43(e) are not applicable.

10 CFR 71.43(g)

Requirement: A package must be designed, constructed, and prepared for transport so that in still air at 38°C (100°F) and in the shade, no accessible surface of a package would have a temperature exceeding 50°C (122°F) in a nonexclusive use shipment or 85°C (185°F) in an exclusive use shipment.

Compliance: Since the components to be shipped have a calculated maximum decay heat load of 0.4 W, thermal analyses were conducted for the ES-3100 package; results are summarized in Appendix 3.6.2. The predicted temperatures, while the package is stored at 38°C (100°F) in the shade, for the drum lid center, and the containment vessel flange, are approximately 38.3°C (101°F). The analysis shows that no accessible surface of the package would have a temperature exceeding 50°C (122°F). Therefore, the requirement of 10 CFR 71.43(g) would be satisfied for either transportation mode (exclusive or nonexclusive use).

10 CFR 71.43(h)

Requirement. A package must not incorporate a feature intended to allow continuous venting during transport.

Compliance. No penetrations, connections, or fittings into the containment vessel exist that would allow venting during transport. The materials of package construction do not provide any pressure buildup during transportation. Four vent holes through the drum are covered with a plastic plug during NCT. Therefore, the requirements of 10 CFR 71.43(h) are satisfied.

2.1.2.2 Component Design Criteria

The ES-3100 packaging/content combination addressed in this safety analysis report is intended to ship contents with a maximum activity of 3.112×10^{-1} TBq (8.41 Ci) at 10 years from initial fabrication; the maximum number of A_2s carried is 290.26 at 50 years following initial fabrication (Table 4.4). Based on the guidance from 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)*, this package is classified in NUREG-1609 (Table 1.1) as a Category II shipping package. However, since the ES-3100 may be used for future contents that exceed 3000 A_2 (under a different SAR and certificate), this package has been classified as a Category I shipping package. Therefore, the containment vessel is designed (using nominal dimensions for each component), fabricated, and inspected in accordance with the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Sect. III, Division I, Subsection NB. The design and subsequent verification comply with the requirements of 10 CFR 71. The structural requirements for the packaging under NCT are addressed in Sect. 2.6. The structural requirements for the packaging under HAC are addressed in Sect. 2.7.

information: a descriptor of the furnace charge in which the test coupons are to represent; the times and dates of the heat treating and the testing; the person responsible for the testing; a statement that these coupons are prior to or after heat treatment; a description of the testing including a sketch of the tensile test specimen; the make, model, serial number, and current calibration data of the testing machine(s) used in the testing; reference to the written testing procedure used; the resulting measure yield strength, ultimate strength, % elongation and % reduction in area; and any pertinent remarks.

2.4 LIFTING AND TIE-DOWN STANDARDS FOR ALL PACKAGES

This section addresses the requirements of 10 CFR 71.45, "Lifting and Tie-Down Standards for All Packages."

2.4.1 Lifting Devices

Requirement. Any lifting attachment that is a structural part of a package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting device under excessive load would not impair the ability of the package to meet other requirements of 10 CFR 71, Subpart E. Any other structural part of the package that could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport, or must be designed with strength equivalent to that required for lifting attachments.

Analysis. The ES-3100 packages, as delivered for transport, have no lifting devices or structural parts that can be used for lifting. Therefore, the lifting devices requirements of 10 CFR 71.45 are not applicable.

2.4.2 Tie-Down Devices

Requirement. If there is a system of tie-down devices that is a structural part of the package, the system must be capable of withstanding, without generating stress in any material of the package in excess of its yield strength, a static force applied to the center of gravity of the package having a vertical component of two times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of ten times the weight of the package with its contents, and a horizontal component in the transverse direction of five times the weight of the package with its contents. Any other structural part of the package that could be used to tie down the package must be capable of being rendered inoperable for tying down the package during transport, or must be designed with strength equivalent to that required for tie-down devices. Each tie-down device that is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet other requirements of this part.

Analysis. The ES-3100 package, as delivered for transport, has no tie-down devices that are structural parts of the package. Therefore, the tie-down requirements of 10 CFR 71.45 are not applicable. Safe tie down and transport of the package is accomplished by two methods explained in *Tie-down Procedures for Type B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*, rev. 5 (Padilla 2004). Method one, shown in Sect. 3.4 of Padilla 2004, is for single-unit tie-down. A drum tie-down adapter is positioned on top of the drum and two chains, passing through the adapter, are attached to equipment positioned on the floor of the transport vehicle. The welded ring on the drum lid helps to initially position this drum tie-down adapter as well as prevent inadvertent assembly damage to the studs and nuts. The second method of securing the ES-3100 package is by the use of the Cargo-Restraint Transporter (CRT) (Padilla 2004, Sect. 6). In this method, a frame is positioned around the base and top of either four, five, or eight packages. These frames are then chained to the floor as depicted in Fig. 6-3 of Padilla 2004. Tension is applied to the chains to eliminate any slack in both methods. The downward load resulting from the chain tensioning is insignificant when compared to the compression loading as specified in 10 CFR 71.71(c)(9).

2.5 GENERAL CONSIDERATIONS

Package structural evaluation is performed by the combination of full scale testing, similarity, and analysis as described in the following sections.

2.5.1 Evaluation by Test

The ES-3100 package was tested in accordance with *Test Plan and Procedures for Certification Testing of the ES-3100 Shipping Package: Final Version w/Field Modifications.* (ORNL/NTRC-013, Vol. 3) Testing of ES-3100 prototype units was performed at the National Transportation Research Center (NTRC), except as noted below. Five full-scale test units were assembled with content weights ranging from 3.6 kg (8 lb) to 50.3 kg (111 lb). One of these test units (TU-4) was subjected to the tests specified in 10 CFR 71.71(c)(5) through (c)(10) excluding (c)(8) prior to the HAC sequential tests stipulated in 10 CFR 71.73 and shown in Table 2.18. Test Unit 2 was chilled prior to being subjected to any structural testing (i.e., 1.2-m NCT drop, 9-m HAC drop, HAC crush, and HAC puncture tests). This unit was chilled to a nominal temperature of -40°C (-40°F). This was accomplished by placing the unit in an environmental chamber in Bldg. 5800 at the Oak Ridge National Laboratory (ORNL) with initially setting of the chamber at ~ -57°C (-70°F) for 24 h. After this initial period, the control on the environmental chamber was set to ~ -43°C (-45°F) for another 48 h. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box. Once transported to the NTRC, sequential structural testing, as shown in Table 2.19 was performed as quickly as possible. The other test units were first subjected to the free drop from 1.2 m (4 ft) test prior to the HAC testing of 10 CFR 71.73. These additional tests were conducted to show that the NCT testing would not reduce the effectiveness of the package to withstand HAC testing. Tables 2.18 and 2.19 summarize the testing procedure and the drop orientations for each ES-3100 test unit.

The essentially unyielding surface used for the 1.2-m (4 ft) drop test was the indoor drop test pad at the NTRC. All 9-m (30-ft) drop and crush tests were conducted at the outside drop pad at the NTRC. The indoor pad consists of a 5.08-cm (2-in.)-thick steel plate embedded inside a reinforced concrete pad ~127 cm (50 in.) thick. The outside drop pad consists of a 10.16-cm (4-in.)-thick steel plate embedded inside a reinforced concrete pad ~167.6 cm (66 in.) thick. An article has been prepared by the NTRC staff to describe the integrity of these test pads (Shappert 1991).

Thermal testing of the five test units was conducted at the No. 3 furnace at Timken Steel Company in Latrobe, Pennsylvania. Prior to the testing, the furnace was characterized for temperature and heat recovery times. Oxygen content in stack gases of the furnace was not monitored because it was not anticipated that any of the package's materials of construction were combustible. There was some burning of the silicone pads which are placed between the inner liners and the top plugs of the packages. However, it should be noted that this furnace employs "pulsed" fire burners. This type of burner is unique in that the natural gas flow rate is varied based on furnace controller demands, but the flow of air through the burners is constant, even when no gas is flowing, thereby ensuring a very rich furnace atmosphere capable of supporting any combustion of package materials of construction. The support stand was welded to a large steel plate which had been placed on the floor of the furnace prior to heating. This steel plate acted as the radiating surface at the bottom of the furnace as well as providing the ability to hold the test stand rigidly in place. Before heating the furnace, workers practiced loading and unloading test packages from the cold furnace to assure that the furnace door would not remain open >90 s during each loading. In fact, the maximum time the door was open during any loading was 64 s.

Damage resulting from physical testing is quantitatively described including photographs in Sect. 2.7. The full-scale test units were fabricated in accordance with drawings created for production hardware. During the procurement process for the full-scale test units, several small changes were suggested by the manufacturer to improve the efficiency and to reduce the cost of fabrication. These changes were incorporated and tested. However, following compliance testing the following changes have been made

to the proposed production hardware. First, a change in the neutron poison from BoroBond4 to Cat 277-4 has been adopted; second, the mid liner design has been changed to a continuous shell by reducing the

Table 2.18. Summary of NCT – 10CFR71.71 tests for ES-3100 package[a]

Test	TU-1 (heavy) 12° Slap-down	TU-2 (heavy) Side Drop	TU-3 (heavy) CG over Top Corner	TU-4 (heavy) Top Down	TU-5 (light) 12° Slap-down
Operational Leak Test (CALT5)	1	1	1	1	1
NCT – 10CFR71.71 (c)(5) Vibration				5	
NCT – 10CFR71.71 (c)(6) Water Spray				2	
NCT – 10CFR71.71 (c)(7) 1.2 m (4 ft) Free Drop	2	2	2	3	2
NCT – 10CFR71.71 (c)(9) Compression				6	
NCT – 10CFR71.71 (c)(10) Penetration				4	

[a] The numbers 1 through 6 indicate the sequence of the tests.

Table 2.19. Summary of HAC – 10CFR71.73 tests for ES-3100 package[a]

Test	TU-1 (heavy) 12° Slap-down	TU-2 (heavy) Side Drop	TU-3 (heavy) CG over Top Corner	TU-4 (heavy) Top Down	TU-5 (light) 12° Slap-down	TU-6[b] 15m Immersion
10CFR71.73 (c) (1) Free Drop 9m (30 ft.)	1	1	1	1	1	
10CFR71.73 (c) (2) Crush 9m (30 ft.)	2	2	2	2	2	
10CFR71.73 (c) (3) Puncture 1m (40 in.)	3,4,5,6	3	3	3	3	
Preheat to above 38 °C (100 °F) before Thermal test	7	4	4	4	4	
10CFR71.73 (c) (4) Thermal 800°C (1475°F)	8	5	5	5	5	
Operational Leak Test of CV (CALT5)	9	6	6	6	6	1
Full Containment Boundary Leak Test (He Leak Test)	10	7	7	7	7	
10CFR71.73 (c) (5) Immersion Test Fissile materials – 0.9 m (3 ft.)	11	8	8	8	8	
10CFR71.73 (c) (6) Immersion Test – All Packages 15 m (50 ft.)						2

[a] The numbers 1 through 11 indicate the sequence of the tests.
[b] TU-6 is only a containment vessel with ballast to ensure non-buoyancy.

diameter of the step in the inner liner for the CV flange from 22.35 cm (8.8 in.) to 21.84 cm (8.6 in.); and third, the silicone rubber pad thickness on the drum assembly bottom liner was increased by ~0.15 cm (0.06 in.). The second change increased the amount of Kaolite 1600 around the CV flange, increased the final volume of the neutron poison, and slightly decreased the volume of the Kaolite 1600 adjacent to the neutron poison. The third change was made to stiffen the rubber pad so it would remain in place during vibration normally incurred during transport. In order to evaluate the impact of these changes, analytical drop simulations were conducted and documented in Appendix 2.10.2. The drop simulations were conducted in the same attitude and temperature regime as those conducted during the compliance testing phase for certification. The results of the structural deformation from compliance testing, drop simulation using BoroBond4 and drop simulations using Cat 277-4 material are presented in Sect. 2.7.8. The analytical structural deformation results shown in Tables 2.52 through 2.61 are nearly identical between the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing. Analytical strain prediction in the structural components are also compared. Although there are minor differences between simulations, the overall magnitude of the strains are very similar. The thermal aspects of these changes are addressed in Sect. 3. NCT and HAC results predicted for an undamaged package show that the change in neutron poison actually reduces the final temperature of the containment vessel components. Therefore, the substitution of Cat 277-4 material and the minor changes in the inner and mid liners for production hardware should not reduce the effectiveness of the packaging when subjected to the regulatory requirements of 10 CFR 71 and the results of compliance testing would be analogous.

The contents used as surrogate payloads for the test units are shown on drawings M2E801580A029, and M2E801580A027. In the light-weight configuration, the contents consist of three 25.4 cm (10 in.) high convenience cans with handles, and 4 silicone rubber pads. These convenience cans, handles and silicone rubber pads are identical to those proposed for transport. The bottom convenience can was filled with tungsten grit until the convenience can and grit assembly weighed ~3 kg (6.6 lb). The actual weight of the tungsten grit was 2.77 kg (6.11 lb). The total content weight for the light- weight content configuration including the convenience cans, silicone rubber pads, can handles, and tungsten grit was ~3.6 kg (8 lb). In the heavy-weight configurations, the surrogate payload consists of three steel cylindrical shaped components with handles, two can spacers filled with BoroBond4 and handles, and 6 silicone rubber pads. The can spacers, handles and silicone rubber pads are identical to those proposed for transport. These components weighed a total of approximately 50 kg (110.2 lb). These different weight assemblies bound the range of possible content configurations and structural deformation resulting from compliance testing. Since the decay heat of the proposed contents is ~0.4 W, little or no impact on the pressure or temperature of the package components will result during NCT. Differences in thermal capacitance of these surrogate payloads from the proposed HEU contents during HAC thermal testing are evaluated in Sect. 3.5.3.

2.5.2 Evaluation by Analysis

Although physical testing of the ES-3100 containers was performed generally at or near room temperature except for Test Unit-2, the effectiveness of the Kaolite insulating material at various temperature extremes was examined through the use of laboratory testing and structural analysis of a similar package, the ES-2LM (Handy 1997). For low-temperature service, Kaolite specimens were tested at -28.89 and -40°C (-20 and -40°F). These tests showed little change in the response of the material as compared to room temperature. Furthermore, structural analyses for bounding soft and stiff material cases were run. The Kaolite 1600 data used in these bounding analyses were from laboratory experiments that used a heavily cured sample (stiff) and a sample to which borax had been added (soft) [Oaks 1997]. Following the production run for the ES-2100 and DPP-2 shipping containers, new casting specimens were available for compression testing. In order to reduce the total cost of Kaolite testing, specimens were tested to approximately -40°C (-40°F) to cover both the cold conditions stipulated in 10 CFR 71.71(c)(2) and the -29°C (-20°F) temperature stipulated in 10 CFR 71.71(b)(1) and at 38°C (100°F). The results of Kaolite

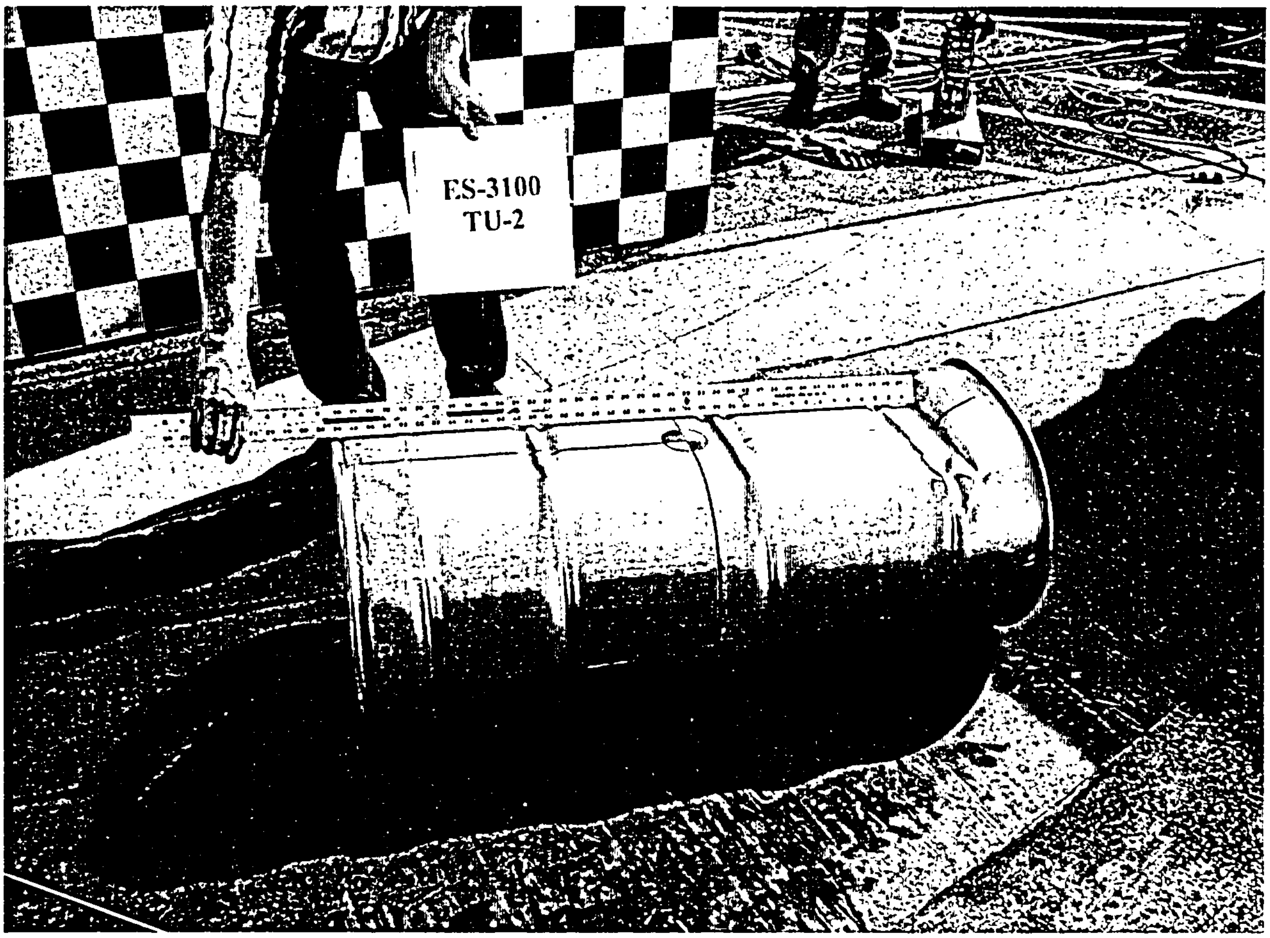

Fig. 2.10. Cumulative damage from 9-m drop and crush testing on Test Unit-2.

2.7.1.3 Corner Drop

Test Unit-3, weighing 203.7 kg (449 lb), was dropped from 9 m (30 ft), with the long axis of the drum at an oblique angle of 24.8° (desired angle was 24.6°) from the impact surface. The mock-up component used in Test Unit-3 is shown on Drawing M2E801580A027 and weighed 50.3 kg (111 lb). The primary concern for this drop orientation was that the combination of plastic deformation at impact on the corner of the drum and the crushing or compacting of the adjacent insulation by the containment vessel flange would result in excessive O-ring temperatures during thermal testing. Another concern was that the mock-up contents would be forced against the containment boundary lid at impact. This, in turn, might yield the flange or closure nut, resulting in loss of containment. The test package made a free fall, with initial contact occurring between the top rim of the drum and the impact surface with the ambient temperature at 28°C (82.4°F). A secondary contact occurred between the bottom drum rim and the impact surface. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage to Test Unit-3 is summarized in Tables 2.29 and 2.30. Pictorials of damage are shown on Test Form 1 of procedure TTG-PRF-08 shown in the test report (ORNL/NTRC-013, Vol. 3) and Fig. 2.11.

Table 2.29. Recorded height damage to Test Unit-3 from 1.2-m and 9-m drop testing

	0°	90°	180°	270°
Pre-drop height (in.)	43.50	43.50	43.50	43.50
Post 1.2-m drop height (in.)	43.00	43.50	43.63	43.50
Post 9-m drop height (in.)	40.63	43.25	43.75	43.38

Table 2.30. Recorded diametrical damage to Test Unit-3 from 1.2-m and 9-m drop testing [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Pre drop test	Post 1.2-m drop test	Post 9-m drop test	Pre drop test	Post 1.2-m drop test	Post 9-m drop test
Top false wire	19.25	19.25	19.25	19.13	19.38	19.19
Top rolling hoop	19.13	19.13	18.63	19.13	19.25	19.88
CG & top rolling hoop	19.13	19.13	19.13	19.13	19.25	19.38
CG rolling hoop	19.13	19.13	19.13	19.13	19.25	19.38
Bottom rolling hoop	19.13	19.13	19.13	19.13	19.25	19.38
Bottom false wire	19.13	19.13	19.13	19.13	19.25	19.25

Fig. 2.11. Test Unit-3 damage from 1.2 and 9-m drop tests.

2.7.1.4 Oblique Drops

Two oblique (slapdown) drops were conducted in the same attitude with maximum and minimum content weights to determine the structural response on the package in accordance with Regulatory Guide 7.8. Paraphrasing Regulatory Position 1.6, a local structural response might be greater during an impact test if the weight of the contents were less than the maximum. Therefore, Test Units-1 and -5 contained the maximum and minimum weight configurations, respectively.

2.7.1.4.1 Test Unit-1 Slapdown

Test Unit-1, weighing 202.3 kg (446 lb) was dropped from 9-m (30 ft) with the long axis of the unit at an oblique angle of 12.2° (desired angle was 12°) to the essentially unyielding surface. The mock-up component used in Test Unit-1 is shown on Drawing M2E801580A027 and weighed 49.90 kg (110 lb). Based on Sect. 3.1 of Regulatory Guide 7.8, the structural performance of the package must be evaluated for the minimum and maximum weight of the contents. Therefore, this unit was tested above the maximum proposed content weight to see if the containment vessel would react differently from the much lighter mock-up used in Test Unit-5 in a similar drop orientation. The primary concern was that the orientation would cause greater angular acceleration of the contents near the package top. This in turn would cause the containment boundary to crush or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. The test package made a free fall with initial contact occurring between the rolling hoops of the drum and the impact surface with the ambient temperature at 28°C (82.4°F). No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage is provided in Tables 2.31, 2.32, and 2.33 and Fig. 2.12.

Table 2.31. Recorded height damage to Test Unit-1 from 1.2-m and 9-m drop testing

	0°	90°	180°	270°
Pre-drop height (in.)	43.50	43.50	43.50	43.50
Post 1.2-m drop height (in.)	43.50	43.50	43.50	43.50
Post 9-m drop height (in.)	42.63	43.38	43.25	43.38
Buckle (in.)	44.50			

Table 2.32. Recorded diametrical damage to Test Unit-1 from 1.2-m and 9-m HAC drop testing [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Pre drop test	Post 1.2-m drop test	Post 9-m drop test	Pre drop test	Post 1.2-m drop test	Post 9-m drop test
Top false wire	19.25	19.13	18.50	19.25	19.25	19.38
Top rolling hoop	19.25	19.00	18.50	19.25	19.25	19.38
CG & top rolling hoop	19.25	19.13	18.50	19.25	19.25	19.38
CG rolling hoop	19.25	19.13	18.63	19.25	19.25	19.38
Bottom rolling hoop	19.25	19.00	18.63	19.25	19.25	19.25
Bottom false wire	19.25	19.00	17.81	19.25	19.25	19.38

Table 2.33. Recorded flat contour damage to Test Unit-1 from 1.2-m and 9-m drop testing

Axial measurement location	Flats width maximum post 1.2-m drop (in.)	Flats width maximum post 9-m drop (in.)
Top false wire	5.25	8.00
Top rolling hoop	4.38	7.38
CG & top rolling hoop	4.50	7.13
CG rolling hoop	3.00	6.38
Bottom rolling hoop	4.00	6.75
Bottom false wire	4.63	10

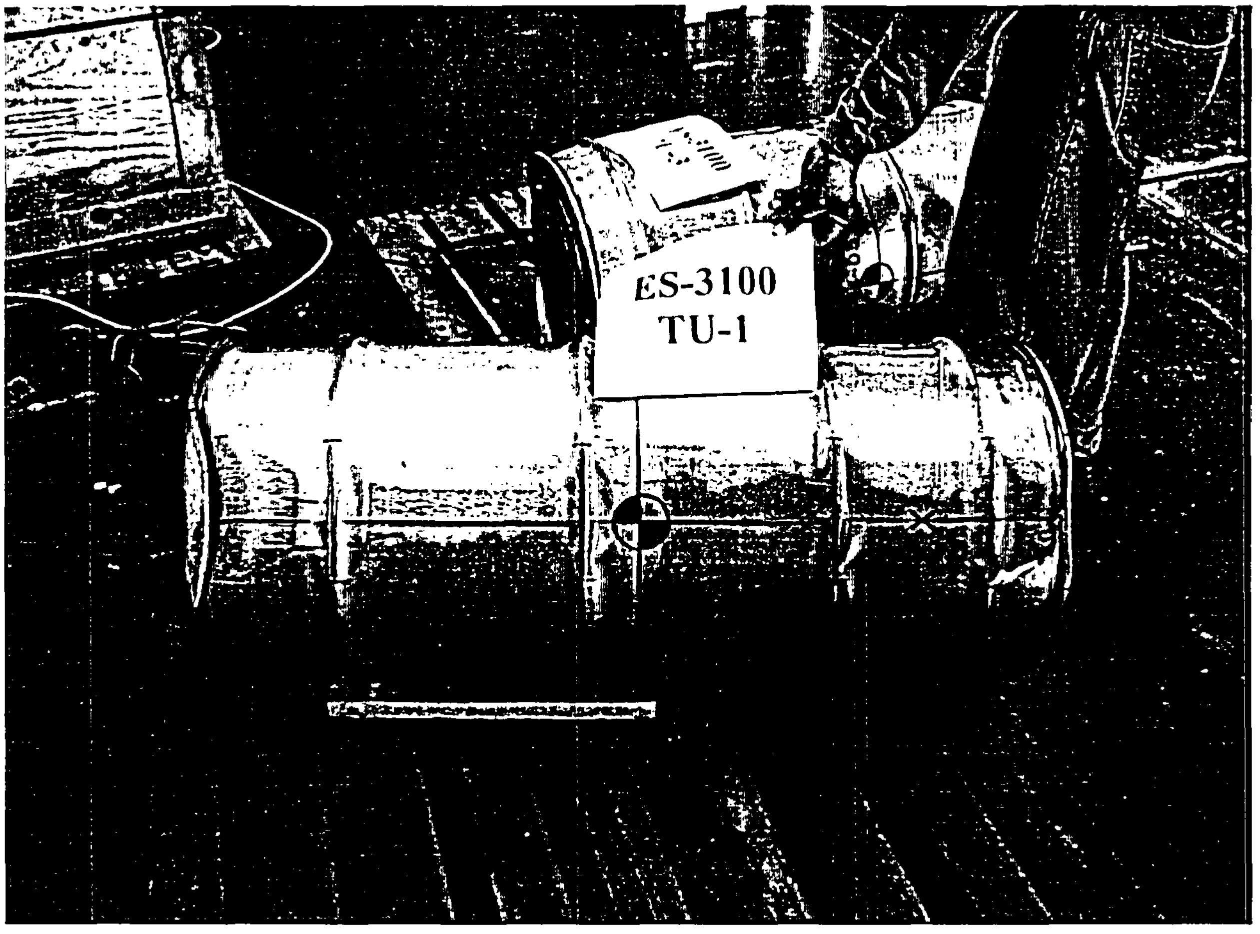

Fig. 2.12. 1.2 and 9-m drop test damage on Test Unit-1.

2.7.1.4.2 Test Unit-5 Slapdown

Test Unit-5, weighing 157.4 kg (347 lb), was dropped from 9-m (30 ft), with the long axis of the drum at an oblique angle of 12.5° (desired angle was 12°) from the impact surface. The mock-up component (Drawing M2E801580A029), weighing 3.6 kg (8 lb), was the hardware with the majority of the mass located near the bottom of the containment vessel (Sect. 2.5.1). Based on Sect. 3.1 of Regulatory Guide 7.8, the structural performance of the package must be evaluated for the minimum and maximum weight of the contents. Therefore, this unit was tested at the minimum proposed weight to see if the containment vessel would react differently from the much heavier mock-up used in Test Unit-1 in a similar drop orientation. The test package made a free fall with initial contact occurring between the bottom rim of the drum and the impact surface with the ambient temperature at 30.6°C (87°F). A secondary contact occurred between the top drum lid and the impact surface. No drum studs, nuts, or washers were lost during this impact test. The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained. A general description of damage is provided in Tables 2.34, 2.35, and 2.36 and Fig. 2.13.

Table 2.34. Recorded height damage to Test Unit-5 from 1.2-m and 9-m drop testing

	0°	90°	180°	270°
Pre-drop height (in.)	43.50	43.50	43.50	43.50
Post 1.2-m drop height (in.)	43.88	43.50	43.50	43.50
Post 9-m drop height (in.)	44.50	43.50	43.38	43.50

Table 2.35. Recorded diametrical damage to Test Unit-5 from 1.2-m and 9-m HAC drop testing [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Pre drop test	Post 1.2-m drop test	Post 9-m drop test	Pre drop test	Post 1.2-m drop test	Post 9-m drop test
Top false wire	19.25	18.88	18.75	19.38	19.38	19.38
Top rolling hoop	19.25	19.00	18.75	19.25	19.25	19.38
CG & top rolling hoop	19.25	19.13	18.75	19.25	19.25	19.38
CG rolling hoop	19.25	19.13	18.75	19.25	19.25	19.25
Bottom rolling hoop	19.25	19.13	18.75	19.25	19.25	19.25
Bottom false wire	19.25	19.13	18.44	19.25	19.25	19.31

Table 2.36. Recorded flat contour damage to Test Unit-5 from 1.2-m and 9-m drop testing

Axial measurement location	Flats width maximum post 1.2-m drop (in.)	Flats width maximum post 9-m drop (in.)
Top false wire	5.38	8.38
Top rolling hoop	4.25	8.38
CG & top rolling hoop	3.88	7.63
CG rolling hoop	2.50	7.50
Bottom rolling hoop	3.25	8.25
Bottom false wire	5.00	9.25

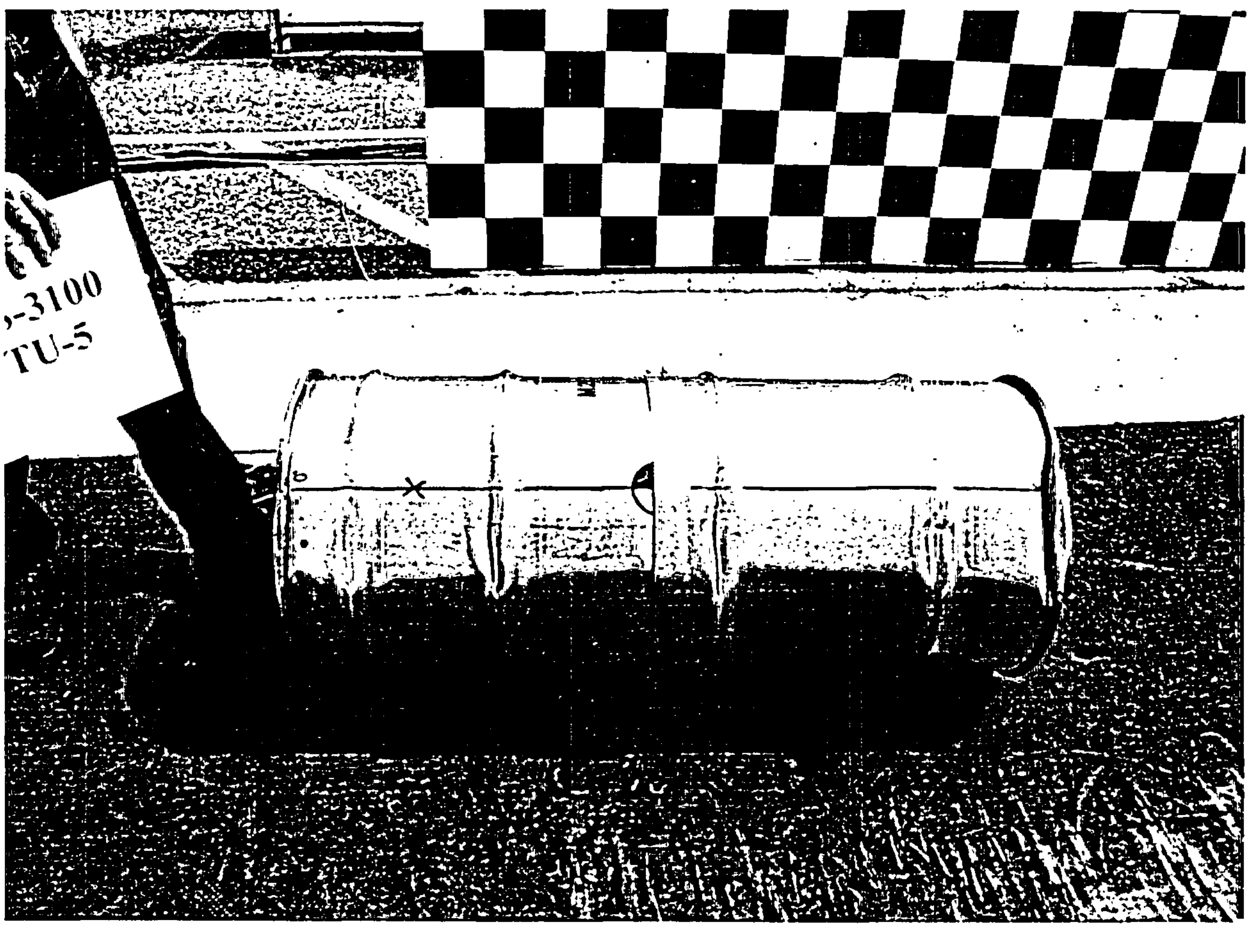

Fig. 2.13. 1.2 and 9-m drop test damage to Test Unit-5.

NB-3230 STRESS LIMITS FOR BOLTS

NB-3232.1 Average Stress

Average stress across a bolt cross section has a different allowable value. Since the CV is threaded to retain the lid special consideration is given to the neck above the lid. Allowable stress on bolts per Appendix III, Article III-2000, of Section III is one-third of the minimum specified yield strength of the material. This is half of the basic allowable but the service stress may be twice the allowable so we are back to an allowable service stress of 12,800 psi. Fig. 5 shows that the peak stress intensity in the neck region is under 6000 psi and the average service stress is much less so the CV is acceptable.

NB-3232.2 Maximum Stress

Maximum service stress in a bolt including bending stress may be three times the basic allowable bolt stress and since the bending component is included in the calculated stress the CV is clearly acceptable.

NB-3227.2 Pure Shear

Pure shear across threads on CV and Closure Nut. These threads are 7.0 inch 8 threads per inch push buttress threads Class 2A fit per ANSI B1.9-1973. The 7 degree slope of the mating surface was accounted for in the finite element models. The threads were not modeled in detail and they are evaluated using a traditional method (B1.1). Internal threads are limiting because the allowable stress for the CV material is about half the allowable stress for the nut material. The appropriate shear area on internal threads is the cylindrical area at the tip of the external thread with minimum height. That is the area at the minimum major diameter of the external thread called $MIN\ D_s$ in B1.9. $MIN\ D_s$ is the nominal D_s, $D - G$, where D is the nominal diameter and G is the allowance for easy assembly minus the tolerance on D. The minimum width of the internal thread at this radius, say t_e, is a function of the theoretical sharp thread form, H, defined as $0.89064p$ where p is the thread pitch, the crest truncation, f ($=0.14532p$), and the sum of radial allowance and tolerances (the *gap*). The *gap* based on thread tolerances is half the tolerance on the pitch diameter and half the tolerance on the major diameter of the thread. The gap should also include any outward radial deformation of the threads. Fig. 11 shows that due to rotation of the flange, the threads in the CV actually move inward and do not increase the gap. In any case the calculated displacements are smaller than the thread tolerances. So, limited to thread properties

$$\text{gap} = \frac{\text{PD tol}}{2} + \frac{\text{G}}{2} + \frac{\text{D tol}}{2} = \frac{0.0101\text{in.}}{2} + \frac{0.0067}{2} + \frac{0.0101\text{in.}}{2} = 0.0134\text{in.}$$

$$t_e = (0.89064p - 0.14532p - gap)(\tan(7^\circ) + \tan(45^\circ))$$
$$= ((0.89064 - 0.14532)(0.125in.) - 0.0134in.)(1.1228)$$
$$= 0.08956in.$$

$$MIN\ D_s = 7in. - 0.0067 - 0.0101in. = 6.9832\text{in.}$$

Three threads are fully engaged so the shear area is at least

$$A_{s,i} = 3(0.08956\,in.)\,\pi\,(6.9832\,in.) = 5.894\,in^2.$$

The shear capacity given the Code limit on shear stress of 0.6 S_m is 0.6 (12,800 psi)(5.894 in.^{2}) = 45,300 lb.

The load due to pressure to the outer edge of the inner O-ring groove is

$$W_{m1} = \pi \frac{101.5\,\text{psi}\,(5.624\,\text{in.})^2}{4} = 2521\ lb.$$

The force due to gasket seating is

$$W_{m2} = 20\,lb./in.\,\pi\left[(5.359\,in. + 0.139\,in.) + (5.859\,in. + 0.139\,in.)\right] = 722.3\,lb.$$

The combined force is 3244 lb. This is much less than the shear capacity so the threads are acceptable for shear.

NB-3232.3 Fatigue Analysis of Bolts

Fatigue analysis of bolts is contained in Section 2 of the Safety Analysis Report for Packaging

CONCLUSIONS

The ES-3100 Containment Vessel meets ASME Code, Section III, requirements for structural design except for fatigue analysis of the threaded closure which was not evaluated. Fatigue analysis of the threaded closure is contained in Section 2 of the Safety Analysis Report for Packaging.

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 1 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

1.0 TABLE OF CONTENTS

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 2 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

2.0 OBJECTIVE

The 7°/45° Buttress threads, specified per ANSI B1.9-1973 7.0-8 Push, used to secure the lid of the ES-3100 Containment Vessel are evaluated for fatigue resistance under normal conditions of use. The evaluation is based on rules in NB-3232.3 from ASME B&PV Code, Section III.

3.0 EVALUATION INPUT (CRITERIA) AND SOURCE

3.1 REFERENCES USED

(B1.9) *Buttress Inch Screw Threads*, ANSI B1.9 – 1973, The American Society of Mechanical Engineers, 1973.

(Code) *Class 1 Components, Section III, Rules for Construction of Nuclear Power Plant Components*, Division 1, 2001 Edition with 2003 Addenda, The American Society of Mechanical Engineers, 2003.

(Drawing) "Containment Vessel Assembly," M2E801580A011, Rev. A, BWXT Y-12, 2003.

(Hammond) "ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel," DAC-EA-900000-A006, Rev. 1, BWXT Y-12, 2004.

(Laughner & Hargan) *Handbook of Fastening and Joining of Metal Parts*, McGraw-Hill Book Company, 1956, pp. 167-168.

(Section II) *Section II, Materials*, Part D – Properties, 2001 Edition with 2003 Addenda, The American Society of Mechanical Engineers, 2003.

(SST/SGT) J. S. Cap, "Recommended Random Vibration and Shock Test Specifications for Cargo Transported on SST and SGT Trailers," letter to distribution, Sandia National Laboratory, Albuquerque, New Mexico, 2002.

3.2 DESIGN CONDITIONS

Hot NCT: Internal pressure of 17.786 psia at 190.06° F.

Cold NCT: Internal pressure of 11.13 psia at -40° F.

3.3 METHODS TO BE USED

A finite element model described in DAC-EA-900000-A006 by Hammond was used. The program was verified by running problems with known solutions. The file name for the model is ES3100CV1. Properties used in the model are shown in Appendix 2.

Even if the torque load in the metal is ignored, the O-rings are compressed at least

Comp. = (0.139 in.-0.004 in.) – (0.114 in.+0.001 in.) = 0.020 in.

and a reduction in compression of 0.004% due to temperature change is insufficient to unload the O-rings enough to allow leakage.

4.3 TRANSPORTATION LOADS

The highest shock acceleration expected during transport is 11g in the vertical direction compared to a maximum horizontal acceleration of 5g per SST/SGT. The contents of the CV are specified to not exceed 90 lbs. The lid can be viewed as three disks, the volumes of which are:

Disk	Volume Formula	Volume, in^3
Top	$\pi(3.98 in.)^2 (0.56 in.)/4$	6.97
Middle	$\pi(6.741 in.)^2 (0.500 in.)/4$	17.84
Bottom	$\pi(5.00 in.)^2 (0.05 in.)/4$	0.98
Sum		25.8

The weight density of the lid material is about 0.29 lb./cu. in. so the weight of the lid is about 7.5 lb. Assume the threads must restrain 100 lbs. as the package is transported. Assuming the CV is upright, gravity provides 1g downward acceleration so the nut must restrain at most a net of 100 lbm. (11g – 1g) = 1,000 lbf. The average stress at the minimum cross section due to shock load is 1,000 lb. / 5.14 in^2 = 195 psi.

4.4 FATIGUE ANALYSIS

For each use of the vessel, the part of the CV equivalent to a bolt is loaded in tension by a torque producing a maximum axial load of 2,000 lb., an average stress of 389 psi and a peak stress (including bending) of 3,563 psi. When the vessel is pressurized to 3.1 psi the peak axial stress is 3,714 psi. This is the peak stress at the undercut which has a stress concentration factor of about 3. Per the Code, paragraph NB-3232.3 (c), the fatigue strength reduction factor for the threads shall not be less than 4 so the fatigue stress on the threads is 3,714 psi (4/3) = 4,952 psi.

Conservatively ignoring the interplay between the CV and the nut and lid, the stress due to impact during transportation is added to produce a maximum tensile stress of 4,952 psi + 195 psi = 5,147 psi. The thermal expansion reduces the preload so it will not extend the stress range. The range is zero to 5,147 psi and the alternating stress is half of the range or 5,147 psi / 2 = 2,574 psi.

The threads are evaluated for cyclic service by comparison with the design Curve A on Table I—9.2.2. For alternating stresses below 23,700 psi the allowable number of cycles exceeds 10^{11}. In every case the stress in the nut has been less than in the CV and since the nut material is also austenitic it does not limit fatigue design.

5.0 CONCLUSIONS

Force due to torquing the nut on the vessel was determined. The actual maximum expected internal pressure is low so the torque load produces much higher stresses in the vessel than pressure but the combined effect of torque and actual pressure was less than the conditions including bounding pressure used in the previous evaluation of the vessel design.

Thermal loads were evaluated relative to gasket compression it was shown that gaskets would remain seated through the maximum expected temperature change.

The threaded components of the ES-3100 Containment Vessel were evaluated per ASME Section III requirements and were found to have an allowable fatigue life in excess of 10^{11} cycles. Since the allowable life of the vessel is limited to a mere 30,000 cycles, the threads do not limit the life of the vessel.

In the successive design impacts (Figure 2.15), a 30-foot impact was followed by a 30-foot crush impact. For these runs, the initial velocities of the shipping package assembly nodes were all defined as 528 in/sec in a direction normal and toward the rigid surface. When the initial impact was over, the run was halted and the velocities of the shipping package assembly nodes were all re-defined as 0.0 in/sec in the restart input file. This file also defined the velocity of the crush plate nodes as 528 in/sec in a direction towards the shipping package.

For the bounding kaolite stiffness runs (Figure 2.1.6), the impacts were successive 4-foot, 30-foot, 30-foot crush and 40-inch punch impacts. The 4-foot, 30-foot and 30-foot crush impacts were carried out as defined previously. The successive punch impact was initiated with the restart input file deleting the crush plate and the rigid plate from the model. The restart input file also redefined the velocity of the shipping package nodes to be towards the punch. This allowed the shipping package to pass through the original position of the rigid surface and impact the punch.

Table 2.1.2 gives the shipping package component masses and weights used in the detailed model analyses. Summations for assembly weights are also listed along with a total assembly weight. As discussed in the Section 2.3 on material models, an initial mass based on preliminary information supplied by the designer is adjusted to match expected hardware weights. This adjustment is required due to the faceted element faces on the inner and outer radius surfaces and the fact that small details are not explicitly modeled (holes, notches, etc). The total weight (full model) of the model is about 427.85 pounds, with 22.4 lb/ft^3 kaolite. The mass moment of inertia for the package is 90.84 in*lb*sec^2 about the global Y axis and the CG is located at Z = 22.4 inches.

Contact surfaces are used to allow adjacent components to separate, bear and/or slide along an adjacent surface. The contact used between the metal components of the model is a LS-Dyna single surface contact. Each node is reactive against every other element in the defined set. The contact between the borobond and its stainless steel liners; and the kaolite and its stainless steel liners is a surface to surface contact. All package nodes are defined as reactive to the rigid surface.

Table 2.1.2 - Analysis Weights for ES-3100

Material Number	Component Description	Run1g-Side mass *	Run1g-Side weight **	Run1hl-Side mass*	Run1hl-Side weight**	Run1hh-Side mass*	Run1hh-Side weight**	Run2e-Lid Corner mass *	Run2e-Lid Corner weight **	Run3b-Lid End mass *	Run3b-Lid End weight **	Run4g-Slapdown mass *	Run4g-Slapdown weight **	Run4h-Slapdown mass *	Run4h-Slapdown weight **
m 1	CV body	2.73E-02	21.10	2.73E-02	21.10	2.73E-02	21.10	2.73E-02	21.10	2.73E-02	21.10	2.73E-02	21.10	2.73E-02	21.10
m 2	CV body at flange	1.73E-03	1.34	1.73E-03	1.34	1.73E-03	1.34	1.73E-03	1.34	1.73E-03	1.34	1.73E-03	1.34	1.73E-03	1.34
m 3	CV lid	9.57E-03	7.39	9.57E-03	7.39	9.57E-03	7.39	9.57E-03	7.39	9.57E-03	7.39	9.57E-03	7.39	9.57E-03	7.39
m 4	CV screw ring	4.27E-03	3.30	4.27E-03	3.30	4.27E-03	3.30	4.27E-03	3.30	4.27E-03	3.30	4.27E-03	3.30	4.27E-03	3.30
m 5	angle	1.69E-02	13.02	1.69E-02	13.02	1.69E-02	13.02	1.69E-02	13.02	1.69E-02	13.02	1.69E-02	13.02	1.69E-02	13.02
m 6	drum	6.02E-02	46.50	6.02E-02	46.50	6.02E-02	46.50	6.02E-02	46.50	6.02E-02	46.50	6.02E-02	46.50	6.02E-02	46.50
m 7	drum bottom head	1.22E-02	9.42	1.22E-02	9.42	1.22E-02	9.42	1.22E-02	9.42	1.22E-02	9.42	1.22E-02	9.42	1.22E-02	9.42
m 8	weld drum to drum bottom head	1.18E-04	0.09	1.18E-04	0.09	1.18E-04	0.09	1.18E-04	0.09	1.18E-04	0.09	1.18E-04	0.09	1.18E-04	0.09
m 9	liner overlap to angle (0.03)	1.36E-04	0.11	1.36E-04	0.11	1.36E-04	0.11	1.36E-04	0.11	1.36E-04	0.11	1.36E-04	0.11	1.36E-04	0.11
m 10	liner (0.06)	3.95E-02	30.51	3.95E-02	30.51	3.95E-02	30.51	3.95E-02	30.51	3.95E-02	30.51	3.95E-02	30.51	3.95E-02	30.51
m 11	liner bottom (0.120) (see m 27 for	1.40E-03	1.08	1.40E-03	1.08	1.40E-03	1.08	1.40E-03	1.08	1.40E-03	1.08	1.40E-03	1.08	1.40E-03	1.08
m 12	lid shells (0.06)	7.25E-03	5.59	7.25E-03	5.59	7.25E-03	5.59	7.25E-03	5.59	7.25E-03	5.59	7.25E-03	5.59	7.25E-03	5.59
m 13	thin lid shell at bolts	1.37E-05	0.01	1.37E-05	0.01	1.37E-05	0.01	1.37E-05	0.01	1.37E-05	0.01	1.37E-05	0.01	1.37E-05	0.01
m 14	lid solids at the lid bolts	5.03E-05	0.04	5.03E-05	0.04	5.03E-05	0.04	5.03E-05	0.04	5.03E-05	0.04	5.03E-05	0.04	5.03E-05	0.04
m 15	lid stiffener	1.39E-03	1.07	1.39E-03	1.07	1.39E-03	1.07	1.39E-03	1.07	1.39E-03	1.07	1.39E-03	1.07	1.39E-03	1.07
m 16	drum bolts	5.06E-04	0.39	5.06E-04	0.39	5.06E-04	0.39	5.06E-04	0.39	5.06E-04	0.39	5.06E-04	0.39	5.06E-04	0.39
m 17	drum bolt nuts	1.20E-03	0.93	1.20E-03	0.93	1.20E-03	0.93	1.20E-03	0.93	1.20E-03	0.93	1.20E-03	0.93	1.20E-03	0.93
m 18	drum bolt washers	4.71E-04	0.36	4.71E-04	0.36	4.71E-04	0.36	4.71E-04	0.36	4.71E-04	0.36	4.71E-04	0.36	4.71E-04	0.36
m 19	plug liner	1.29E-02	10.00	1.29E-02	10.00	1.29E-02	10.00	1.29E-02	10.00	1.29E-02	10.00	1.29E-02	10.00	1.29E-02	10.00
m 20	plug kaolite	1.26E-02	9.70	1.52E-02	11.70	1.52E-02	11.70	1.26E-02	9.70	1.26E-02	9.70	1.26E-02	9.70	1.26E-02	9.70
m 21	drum kaolite	1.43E-01	110.08	1.72E-01	133.03	1.72E-01	133.03	1.43E-01	110.08	1.43E-01	110.08	1.43E-01	110.08	1.43E-01	110.08
m 22	drum borobond	5.66E-02	43.70	5.66E-02	43.70	5.66E-02	43.70	5.66E-02	43.70	5.66E-02	43.70	5.66E-02	43.70	5.66E-02	43.70
m 24	lower internal cv mass	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69
m 25	middle internal cv mass	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69
m 26	upper internal cv mass	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69	4.75E-02	36.69
m 27	liner bottom solids	9.87E-04	0.76	9.87E-04	0.76	9.87E-04	0.76	9.87E-04	0.76	9.87E-04	0.76	9.87E-04	0.76	9.87E-04	0.76
m 29	visual rigid plane	7.80E-04	0.60	7.80E-04	0.60	7.80E-04	0.60	9.00E-04	0.69	8.00E-04	0.62	9.00E-04	0.69	9.00E-04	0.69
m 30	crush plate	1.42E+00	1099.99	1.42E+00	1099.99	1.42E+00	1099.99	1.42E+00	1099.99	1.42E+00	1099.99	1.42E+00	1099.99	1.42E+00	1099.99
m 31	punch	8.24E-02	63.62	8.24E-02	63.62	8.24E-02	63.62	8.24E-02	63.62	8.24E-02	63.62	8.24E-02	63.62	8.24E-02	63.62
m32	silicon rubber	1.65E-03	1.27	1.65E-03	1.27	1.65E-03	1.27	1.65E-03	1.27	1.65E-03	1.27	1.65E-03	1.27	1.65E-03	1.27
	dyna total model weight	2.06E+00	1592.05	2.09E+00	1617.00	2.09E+00	1617.00	2.06E+00	1592.15	2.06E+00	1592.07	2.06E+00	1592.15	2.06E+00	1592.15
	CV lid and nut ring		10.68		10.68		10.68		10.68		10.68		10.68		10.68
	CV body wt		22.44		22.44		22.44		22.44		22.44		22.44		22.44
	CV total wt		33.12		33.12		33.12		33.12		33.12		33.12		33.12
	plug liner and kaolite		19.70		21.69		21.69		19.70		19.70		19.70		19.70
	liner + angle		45.49		45.49		45.49		45.49		45.49		45.49		45.49
	drum body + kaolite + borobond4		256.94		279.90		279.90		256.94		256.94		256.94		256.94
	drum + lid + plug + kaolite + borobond4		284.65		309.60		309.60		284.65		284.65		284.65		284.65
	internal cv masses		110.08		110.08		110.08		110.08		110.08		110.08		110.08
	Total Package Weight		427.85		452.79		452.79		427.85		427.85		427.85		427.85
	Crush Plate Weight		1099.99		1099.99		1099.99		1099.99		1099.99		1099.99		1099.99
	Punch Weight		63.62		63.62		63.62		63.62		63.62		63.62		63.62
	Visual Rigid Plane		0.60		0.60		0.60		0.69		0.62		0.69		0.69
	Total Model Weight		1592.05		1617.00		1617.00		1592.15		1592.07		1592.15		1592.15

* - Mass is for the 1/2 model and is units of (pound * second^2) / inch

** - Weight is for the total package (2 x model weight) and is in units of pounds.

Friction factors are used in the contact surfaces of the models. Generally speaking, a static coefficient of 0.3 and a dynamic value of 0.2 is used. For the silicon rubber parts, a static coefficient of 0.6 and a dynamic value of 0.5 is assumed. The general factors of 0.3 (static) and 0.2 (dynamic) are also used for the shipping package contact with the rigid surface.

The design of the ES-3100 and the impact configurations are symmetrical. An analytical half model is used with conditions of symmetry defined for all nodes initially on the plane of symmetry. The drum bolting and the CV nut ring are modeled with surfaces initially in contact, but not pre-loaded. The CV is not pressurized. Gravity is included in the models.

The model typically used for a drum welded stud which secures the lid is shown in Figure 2.1.7. The mesh footprint in the stud is mirrored in the angle such that there is a one-to-one match of the stud nodes to angle nodes on the mating surface. The lower nodes on the studs are allowed to merge with the angle nodes. This is structurally conservative at the stud/angle intersection due to the fact that in the stud arc welding process a shoulder boss (area greater than the nominal stud area) is formed. The radius of the modeled studs is such that the faceted area of the stud model equates to the tensile stress area of the studs. Similarly to the stud/angle nodes, the nut/stud nodes are positioned and allowed to merge. The lid is modeled with shell elements, however, at the radius around each stud a transition to brick elements is made. This allows frictional bearing of the lid thickness onto the stud shank to be modeled. This modeling approach has been used and accepted for NNSA-licensed shipping packages that were subject to independent review and verification analysis (i.e., DPP-2 and ES-2100).

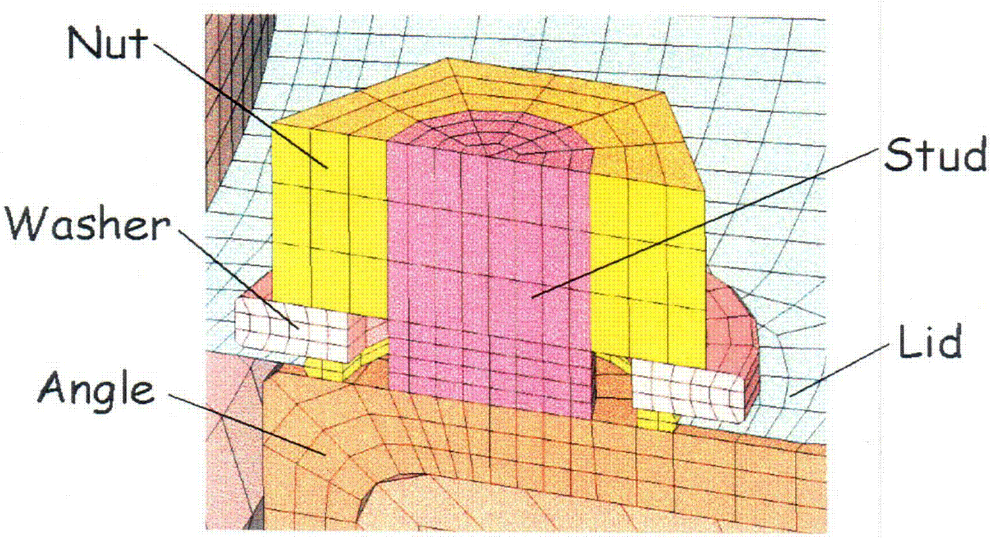

Figure 2.1.7 - Localized Model of a Stud

C01

2.2 Model Description - Simplified Model

A series of punch impact runs were made on a simple model of the ES-3100 shipping container by varying the angle between the container liner and the punch, see Figure 2.2.1. In Figure 2.2.1, the position of the punch relative to the drum is shown with the angles in degrees. The purpose of the punch runs was to determine the response of the stainless steel drum liner due to the angled punch impacts. A series of eight, angled drops as shown in Figure 2.2.2 and described in Table 2.2.1 were made. In Figure 2.2.2, the punch is held stationary and the drum is positioned relative to the punch. The center of gravity of the shipping package was located directly above the side of the punch as shown in Figure 2.2.1. The initial velocity of the container is parallel to the axis of the punch as shown in Figure 2.2.2.

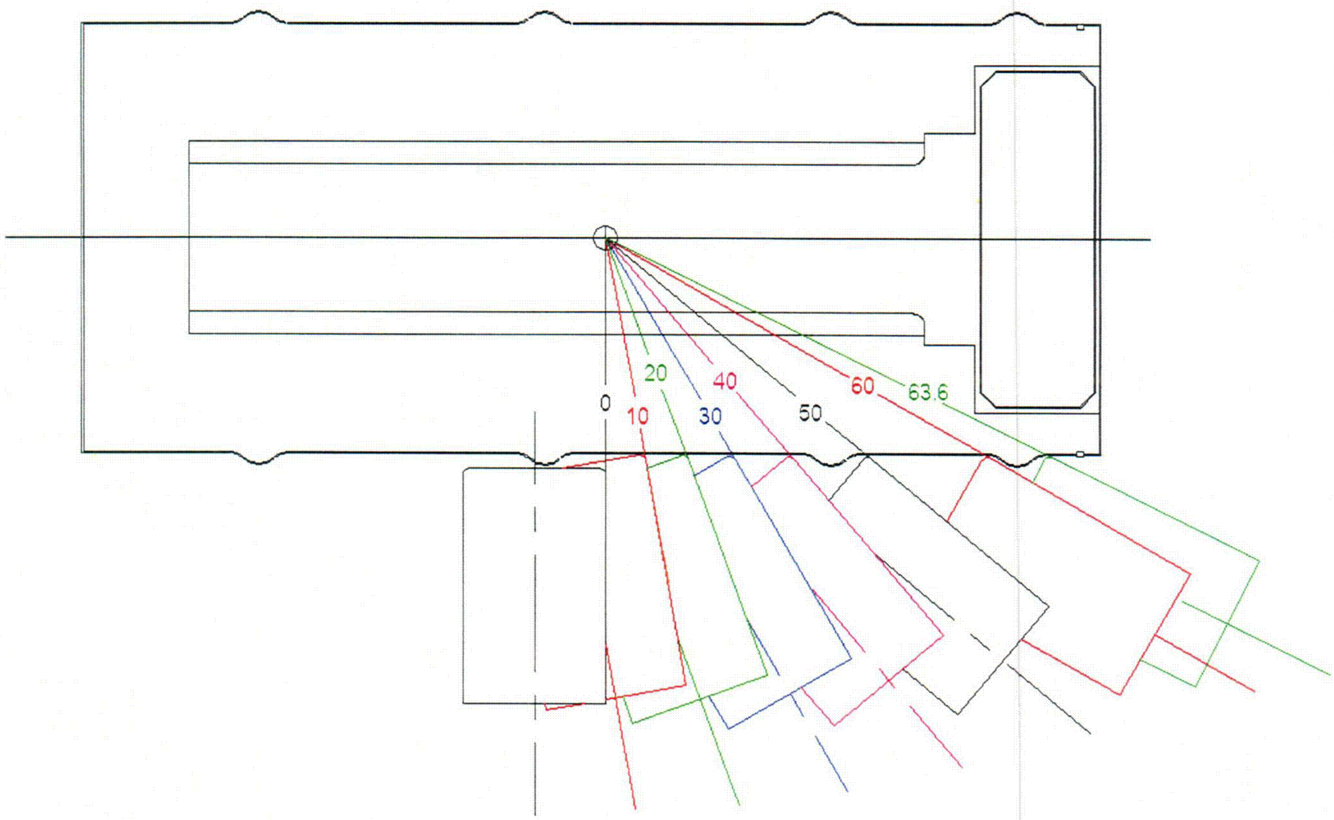

Figure 2.2.1 - Punch Angles on the Drum Liner

A simplified model of the ES-3100 was derived from the more detailed model (described in Section 2.1) for this series of runs. The model detail needed in the 4-foot, 30-foot, crush, and successive punch impact is not needed for the series of punch impacts. The purpose of the series of punch impacts is to evaluate the response of the drum skin to various punch angles.

C02

2.3.1 304L Stainless Steel

The material 304L is used for the CV components except the nut ring. A software database obtained from Lawrence Livermore National Lab personnel is used to obtain the 304L material data which is reproduced below.

```
Material density . . . . . .      0.28600   lb/in**3
Young's Modulus. . . . . . .      2.800E+07 psi
Shear Modulus. . . . . . . .      1.085E+07 psi
Bulk Modulus . . . . . . . .      2.222E+07 psi
Poisson's ratio. . . . . . .      0.2900
Yield stress at offset . . .  32000.0       psi
Engineering ultimate stress.  85000.0       psi
Elongation at failure. . . .     57.00      %
Yield offset . . . . . . . .      0.20000   %
---------- Calculated values -----------------------
Strain Hardening equation       s   = s0 e**m
Equation constants              s0 = 160455    m   = 0.27916
Yield point                     sy =  21735    ey  = 0.00078
Ultimate (Engineering)          Su =  85000    Nu  = 0.32202
Ultimate (True)                 sut= 112372    eut= 0.27916
Failure  (True)                 sft= 168989    eft= 1.20397
Energy to ultimate                     24605 in-lb/in**3
```

The LS-Dyna power law plasticity model (*MAT_POWER_LAW_PLASTICITY) is used for 304L. The material model is:

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

were, K = strength coefficient = 160455 (psi)
m = hardening exponent = 0.27916

The density listed in the reference was an initial density (0.286 lb/in^3) and equates to an initial mass density of 7.4093e-4 lb*sec^2/in^4.

2.3.2 A-479 Nitronic-60

The CV nut ring is modeled with A-479 Nitronic-60 properties. The Reference 5.4 was used to obtain the following material data for the S21800 material.

Tensile Strength	95 ksi
Yield Strength	50 ksi
Elongation	35%

The modulus of elasticity is assumed to be 26.2e6 psi.

From this data the following tangent modulus was calculated for the LS-Dyna, *MAT_PLASTIC_KINEMATIC material model.

$$\varepsilon = \frac{\sigma}{E} = \frac{50000psi}{26.2e6psi} = 0.00192in/in$$

$$E_{tan} = \frac{95000psi - 50000psi}{0.35 - 0.00192} \approx 129000psi$$

A poisson's ratio of 0.298 was used. A density of 0.2754 lb/in^3 was initially used. This equates to an initial mass density of 7.1347 lb*sec^2/in^4.

2.3.3 304 Stainless Steel

The general shipping container components were modeled as 304 stainless steel. The LS-Dyna material model *MAT_POWER_LAW_PLASTICITY was used for the general container components. The 304 material data was obtained from a software database obtained from Lawrence Livermore National Lab personnel and is reproduced below.

```
Material density . . . . . .      0.29000   lb/in**3
Young's Modulus. . . . . . .      2.810E+07 psi
Shear Modulus. . . . . . . .      1.089E+07 psi
Bulk Modulus . . . . . . . .      2.230E+07 psi
Poisson's ratio. . . . . . .      0.2900
Yield stress at offset . . .  34000.0       psi
Engineering ultimate stress.  87000.0       psi
Elongation at failure. . . .     57.00      %
---------- Calculated values ----------------------
Strain Hardening equation      s  = s0 e**m
Equation constants             s0 = 162738    m  = 0.27208
Yield point                    sy =  23729    ey = 0.00084
Ultimate (Engineering)         Su =  87000    Nu = 0.31269
Ultimate (True)                sut= 114204    eut= 0.27208
Failure  (True)                sft= 167370    eft= 1.10866
```

Similar to section 2.3.1, the power law coefficients for the 304 model used for the general shipping container components were:

K = strength coefficient = 162738 (psi)
m = hardening exponent = 0.27208

The 0.290 lb/in^3 density equates to 7.513 e-4 lb*sec^2/in^4 for the initial mass density.

The drum studs were modeled using the *MAT_PLASTIC_KINEMATIC material model in LS-Dyna using the following 304 material properties. This material model allowed material failure to be used for the studs. With material failure, LS-Dyna removes elements which reach the defined failure strain. The following elastic-plastic model was derived from the above material properties.

Modulus of Elasticity = 2.81e7 psi†
Poisson's Ratio = 0.29
Yield = 34000 psi
Plastic Modulus = 93180 psi
Failure Strain = 0.57 in/in

The modeling of the drum studs with engineering stress/strain data curve is conservative from a design standpoint. This approach has been used and accepted for NNSA-licensed shipping packages that were subject to independent review and verification analysis (i.e., DT-22 and DT-23).

† - Note: the value of 2.9e7 psi (vs 2.81e7 psi) was inadvertently used in the analysis for the modulus of elasticity. This is seen to cause minimal concern due to the minimal energy absorption in the elastic range.

2.3.4 Bronze

The drum lid nuts are made of bronze. A software database obtained from Lawrence Livermore National Lab personnel was used to obtain the material data which is reproduced below.

```
Material . . . .bronze commercial cu.9 zn.1 ½ hard
Material density . . . . . .      0.31800   lb/in**3
Young's Modulus. . . . . . .      1.700E+07 psi
Shear Modulus. . . . . . . .      6.391E+06 psi
Bulk Modulus . . . . . . . .      1.667E+07 psi
Poisson's ratio. . . . . . .      0.3300
Yield stress at offset . . .  45000.0       psi
Engineering ultimate stress.  52000.0       psi
Elongation at failure. . . .     15.00      %
---------- Calculated values ----------------------
Strain Hardening equation      s   = s0 e**m
Equation constants             s0 =  70989    m   = 0.09191
Yield point                    sy =  40775    ey  = 0.00240
Ultimate (Engineering)         Su =  52000    Nu  = 0.09626
Ultimate (True)                sut=  57006    eut= 0.09191
```

The LS-Dyna power law model was used for the bronze material. The coefficients used were:

K = strength coefficient = 70989(psi)
m = hardening exponent= 0.09191

The density of 0.318 lb/in^3, or 8.2371e-4 lb*sec^2/in^4 was the initial mass density.

2.3.5 Kaolite 1600

Kaolite 1600 properties were used to model the drum and plug kaolite. The LS-DYNA honeycomb material model (*MAT_HONEYCOMB) used for the ES-3100 has been shown to be a good representation of the Kaolite material and approved for NNSA-licensed shipping packages that were subject to independent review and verification analysis (i.e., DPP-2 and ES-2100). There have been several testing programs to determine the structural properties of Kaolite since 1995. Each time new data is obtained, it is compared to the old data to maintain enveloping upper and lower bound stiffness curves. The lower stress/strain portion of the curves presented in this section is shown in Figure 2.3.5.1 below. Each curve shown in Figure 2.3.5.1 is documented in the following sub-sections. The Kaolite test data was obtained from constrained test specimens. For the constrained Kaolite test data, the material data is the same for uniaxial and volumetric strain.

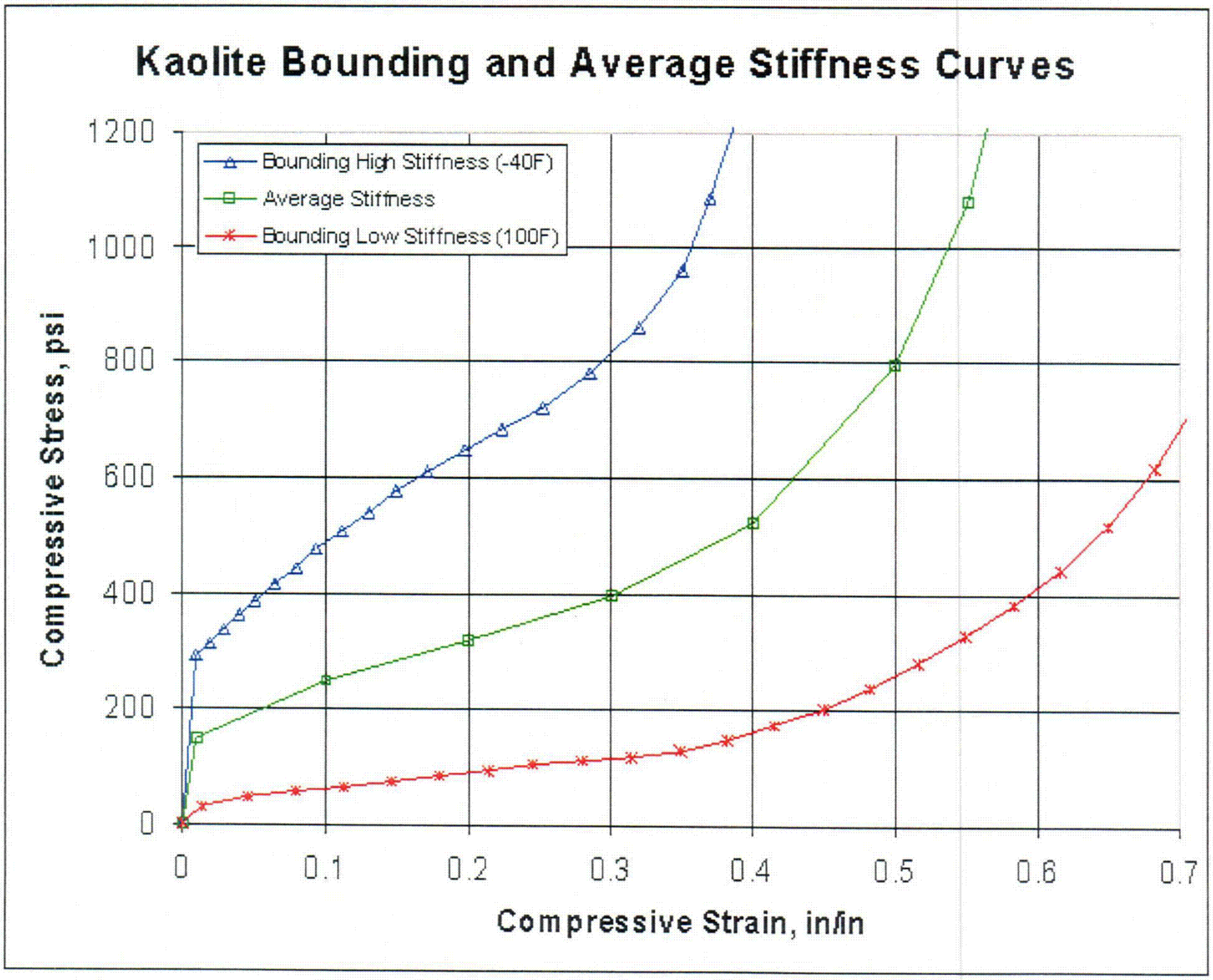

Figure 2.3.5.1 - Bounding Kaolite and Average Stiffness Curves

C03

The Young's Modulus for the compacted kaolite material is taken as the slope of the last two data points.

$$\frac{40000psi - 10000psi}{0.90in/in - 0.87in/in} = 1.0e6psi$$

The initial slope is taken as the uncompressed modulus of elasticity.

$$E_{uncompressed} = \frac{29.psi - 0.0psi}{0.0132 - 0.0} = 2197psi$$

Assuming a low poisson's ratio, the shear modulus is,

$$G \approx \frac{E}{2} = 1099\ psi$$

A low poisson's ratio is assumed, 0.01. Full compaction is also assumed at a relative volume of 0.10. The density used is 27 lb/ft^3, or 4.0479e-5 lb*sec^2/in^4.

2.3.5.3 Kaolite 1600 Upper Bound Stiffness

The upper bound stiffness of the kaolite 1600 material is an enveloping curve obtained from two sets of material test data. Table 2.3.5.3.1 shows the digital values of the curve.

The Young's Modulus for the compacted kaolite material is taken as the slope of the last two data points.

$$\frac{40000psi - 22000psi}{0.88in/in - 0.85in/in} = 6.0e5\ psi$$

The initial slope is taken as the uncompressed modulus of elasticity.

$$E_{uncompressed} = \frac{292.1psi - 0.0psi}{0.01 - 0.0} = 29210psi$$

Assuming a low poisson's ratio, the shear modulus is,

$$G \approx \frac{E}{2} = 14605\ psi$$

A density of 27 lb/ft^3 is used as in the low stiffness run. A low poisson's ratio is assumed, 0.01. Full compaction is also assumed at a relative volume of 0.12.

Table 2.3.5.3.1 - Upper Bounding Kaolite Curve		
Strain, in/in	Stress, psi	Origin
0	292.1	Summer 2004 Material Testing
0.01	292.1	
0.019	313.3	
0.029	336.1	
0.04	360.5	
0.051	386.6	
0.064	414.3	
0.079	443.6	
0.094	474.5	
0.111	506.9	
0.13	540.7	
0.15	575.7	
0.172	611.6	
0.197	647.9	
0.224	684.1	
0.253	719.6	
0.285	780	assumed for smooth transition†
0.32	860	
0.3504	958	DPP2 Shipping Container Calculation
0.3696	1086	
0.3888	1231	
0.45	2000	assumed for lock-up†
0.5	3000	
0.6	6000	
0.7	10000	
0.8	16000	
0.85	22000	
0.88	40000	

† - Assumed values for transition and lock-up

The bulk modulus is calculated as:

$$BulkModulus = \frac{E}{3(1-2\nu)} = \frac{1.991e6\ psi}{3(1+2(0.33))} = 1.952e6\ psi$$

Volumetric response data for the HABC material is lacking. A volumetric response will be derived from the one dimensional compressive test data. The HABC material is assumed to behave as a homogeneous, isotropic material.

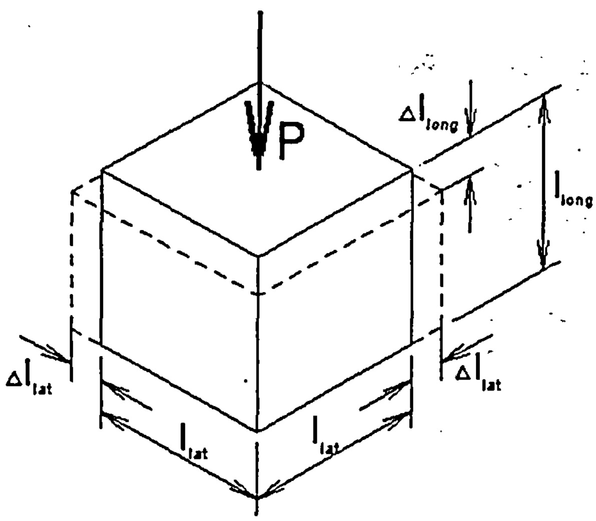

Figure 6.2.1.1 - Assumed Response of a Unit Cube

Using Figure 6.2.1.1 and noting the following definitions,

$$\varepsilon_{long} = \frac{\Delta l_{long}}{l_{long}}\ ;\ \varepsilon_{lat} = \frac{\Delta l_{lat}}{l_{lat}}\ ;\ \nu = \frac{\varepsilon_{lat}}{\varepsilon_{long}}$$

$$\varepsilon_{lat} = \nu\ \varepsilon_{long}$$

$$l_{lat} = l_{long} = l$$

The initial volume is, l^3, and the final volume is:

$$final\ volume = (l - \Delta l_{long})(l + \Delta l_{lat})(l + \Delta l_{lat})$$

Substituting the above definitions into this equation and simplifying results in the following expression for the final volume.

$$final\ volume = l^3(1 - \varepsilon_{long})(1 + \nu\varepsilon_{long})^2$$

The relative volume then is,

$$V = \frac{current\ volume}{initial\ volume} = (1 - \varepsilon_{long})(1 + \nu\varepsilon_{long})^2$$

The volumetric strain then is:

$$volumetric\ strain = \ln V$$

Using this and P = σ/3, a pressure vs volumetric strain curve is derived. The pressure cut off for tension is derived from the tensile failure of 234.7 psi. The pressure cut off for the material model is: $P = \frac{\sigma}{3} = \frac{234.7\ psi}{3} = 78.2\ psi.$

The constants a_0, a_1, and a_2 are yield function constants defined in the material model. To eliminate the pressure dependence of the yield strength, $a_1 = a_2 = 0$ and $a_0 = \sigma^2_y/3 = (1165.8\ psi)^2/3 = 4.530e5\ psi^2$. The following material model was used for the upper stiffness bound of the HABC material (-40°).

LS-Dyna Material Model	*MAT_SOIL_AND_FOAM
Density	1.5742e-4 lb-sec^2/in^4 (105 lb/ft^3)
Shear Modulus	7.485e5 psi
Bulk Modulus	1.952e6 psi
A_0	4.530e5 (psi)^2
A_1	0
A_2	0
Tensile Cutoff	78.2 psi

Volumetric Strain Data vs Pressure:

Volumetric Strain, in^3/in^3	Pressure, psi
0	0
-3.4380E-05	67.100
-1.3300E-04	187.300
-2.5971E-04	294.367
-4.4481E-04	374.067
-8.8812E-04	416.567
-3.4612E-03†	433.333†
-1.6787E-01†	566.667†
-5.5498E-01†	1000.000†
-1.1409E+00†	100000.000†

† - assumed values to achieve numerical lock-up.

6.2.2 HABC at 70° F

Poisson's ratio is given as 0.28 by the testing. The modulus of elasticity was taken to be the slope of the load deflection curve for the first data point.

$$E = \frac{\sigma}{\varepsilon} = \frac{150.3psi - 0psi}{(219.8e-6) - 0} = 6.838e5psi$$

The shear modulus is then calculated as:

$$ShearModulus = \frac{E}{2(1+\nu)} = \frac{6.838e5\ psi}{2(1+0.28)} = 2.671e5psi$$

The bulk modulus is calculated as:

$$BulkModulus = \frac{E}{3(1-2\nu)} = \frac{6.838e5\ psi}{3(1+2(0.28))} = 5.180e5\ psi$$

The pressure cut off is calculated as P=184 psi / 3 = 61.3 psi and the constants a_0 is calculated as (983psi)^2/3 = 3.221e5 psi^2. The following material model was used for the 70°F runs of the HABC material.

The relatively high level of plastic strain in the HABC-run2e liner is a surface strain. Investigation shows that the membrane strain is about 0.2205 in/in, or well below the expected failure level. The deformation/fringe plot shows that the region of high strain is relatively local at the attachment of the liner to the angle. The plot also shows that it is the result of crimping or folding of the liner due to the relatively stiffer angle. Any tearing that might take place would be limited, evidence the local concentration of fringe levels.

Table 8.0.1 - ES-3100 HABC Shipping Package Summary of Component Maximum Effective Plastic Strain (in/in)

Material	Description	HABC-run1hl Side - Lower Bound Kaolite (Section 7.1)			HABC-run1hh Side - Upper Bound Kaolite (Section 7.2)		
		4-foot	30-foot	Centered Crush	4-foot	30-foot	Centered Crush
1	CV Body	0.0185	0.0195	0.0206	0.0238	0.0347	0.0525
3	CV Lid	0.0001	0.0002	0.0002	0.0000	0.0001	0.0004
4	CV Nut Ring	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005
5	Angle	0.0055	0.0780	0.1142	0.0061	0.0632	0.0845
6	Drum	0.1599	0.2251	0.5139	0.1207	0.2296	0.2814
7	Drum Bottom	0.1033	0.2126	0.3562	0.1252	0.2517	0.2827
10	Liner	0.1045	0.1078	0.1593	0.0991	0.1184	0.2022
12	Lid	0.1393	0.5790	1.2580	0.1604	0.4063	0.6413
15	Lid Stiffener	0.0004	0.0093	0.0515	0.0006	0.0076	0.0171
16	Lid Studs	0.0000	0.1140	0.5121	0.0000	0.1306	0.2364
17	Lid Stud Nuts	0.0000	0.0000	0.0005	0.0000	0.0004	0.0018
18	Lid Stud Washe	0.0194	0.0194	0.0693	0.0411	0.0424	0.0439
19	Plug Liner	0.0022	0.0958	0.1220	0.0045	0.1072	0.1286

Material	Description	HABC-run2e Corner (Section 7.3)		HABC-run3b End (Section 7.4)		HABC-run4g Slapdown (Section 7.5)		HABC-run4ga Slapdown (Section 7.6)	
		Impact	Crush	Impact	Crush	Impact	Offset Crush	Impact	Centered Crush
1	CV Body	0.0371	0.0371	0.0028	0.0083	0.0376	0.0564	Same as HABC-Run4g Impact Results	0.0643
3	CV Lid	0.0051	0.0051	0.0072	0.0072	0.0004	0.0013		0.0018
4	CV Nut Ring	0.0002	0.0002	0.0011	0.0011	0.0000	0.0001		0.0000
5	Angle	0.0394	0.0462	0.0287	0.0308	0.0900	0.1070		0.0944
6	Drum	0.3247	0.3830	0.0557	0.1237	0.3018	0.3920		0.3443
7	Drum Bottom	0.0000	0.0761	0.0031	0.0267	0.2879	0.2879		0.3000
10	Liner	0.3983	0.5254	0.0607	0.3812	0.1458	0.2060		0.2846
12	Lid	0.2791	0.3622	0.1082	0.1389	0.5278	0.9689		0.5828
15	Lid Stiffener	0.0272	0.0272	0.0069	0.0100	0.0213	0.0894		0.0288
16	Lid Studs	0.5233	0.5598	0.0962	0.1535	0.1892	0.4018		0.2390
17	Lid Stud Nuts	0.2260	0.2266	0.0166	0.0173	0.0000	0.0028		0.0000
18	Lid Stud Washe	0.1528	0.1528	0.0506	0.0506	0.0724	0.0790		0.0775
19	Plug Liner	0.1152	0.1166	0.0670	0.0960	0.1258	0.2665		0.1644

9.0 Comparison of Borobond Cylinder and HABC Cylinder Models

Part A of this calculation (Sections 2 through 5) apply to the initial, borobond neutron absorber model. Section 3.12 compared the borobond model results to the physical tested specimen. Part B (Sections 6 through 8) apply to the HABC redesigned neutron absorber model. Section 7.7 compares the HABC model to the physical tested specimen. The HABC model was derived from the initial borobond model, with changes detailed in Section 6. Section 6.1 gives the configuration changes and Section 6.2 gives the material model derivation for the HABC neutron absorber.

The borobond and the HABC materials are similar in nature in that they are castable, cement type materials. The LS-Dyna material model used in both analytical simulations was the *MAT_SOIL_AND_FOAM model. Similar approaches were taken for both the borobond and the HABC to match the material test results to the needed material properties in the analytical model. The approach is shown explicitly for the HABC material model in Section 6.2. The borobond model used in the Part A models, was also used in the Highly Enriched Uranium Materials Facility (HEUMF) storage pallet modeling, testing and qualification.

The CV body cylinder has an outside diameter of about 5.6 in. A minimum liner diameter of about 5.3 inches was found to occur in the borobond slapdown runs (4g, 4ga, 4h and 4ha). This minimum occurred at several locations along the liner length, and also near the CV flange. A somewhat similar response is noted for the HABC models, but with more deflection near the mid-height of the CV cavity. A minimum liner diameter of about 5.2 inches near the CV flange is noted in slapdowns HABC-run4g and 4ga. However, a minimum diameter of about 4.5 in is noted in HABC-run4ga near the mid-height of the CV body. This region of the CV body is remote from the bottom head or the flange and plastic strains in the body are relatively low (compare Figures 3.8.2 and Figure 7.6.4). The region of concern, near the CV flange, experiences about the same deformation (5.3 in vs 5.2 in).

A significant demand is placed on the lid and the studs in both the borobond and the HABC model side and slapdown impacts. This is a precipitate of the design attempt to minimize the number of studs securing the lid. The lid power law material model does not allow for element failure, whereas the model used for the studs (elastic-plastic) did allow element failure to be modeled. The effective plastic strain in bending and membrane reach significantly high levels (about 1.0 strain) in the lid. The regions of elevated plastic strain in the lid are shown to be localized at the stud holes. The studs also reached elevated levels of plastic strain. Investigation into the time history of the demand placed on the lid and the studs reveals that the lid reaches the elevated levels earlier in the impact, and therefore tearing of the lid would be expected. The tearing of the lid is expected to relieve the

OO-PP-1210, *Procurement Specification for the MD-1 Containment Vessel.*

ORNL/NTRC-013/V1-3, rev. 0, *Test Report of the ES-3100 Package*, UT-Battelle, Oak Ridge Natl. Lab., Natl. Transportation Research Center, Sept. 10, 2004.

Padilla, K. J., *Tie-down Procedures for Type B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*, rev. 5, Sandia Natl. Labs., Albuquerque, N.M, Jan. 15, 2004. OFFICIAL USE ONLY.

Parker O-ring Handbook, Catalog ORD 5700A/US, Parker Hannifin Corp., O-Ring Div., Lexington, Ky., 2001.

Pro/ENGINEER™, Wildfire release, Parametric Technology Corp., Needham, Mass., date code 2003490.

Regulatory Guide 7.6, rev. 1, *Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels*, U.S. NRC, March 1978.

Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks*, U.S. NRC, May 1977.

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. NRC, June 1991.

Shappert, L. B., "Test Facilities for Radioactive Material Transport Packages (Oak Ridge National Laboratory, USA)," RAMSTRANS, 2 (4/5), 73–79, Nuclear Technol., 1991.

Slapdown: A Rigid Body Dynamics Code, Version 05.20.93, Sandia Natl. Lab.

SNT-TC-1A-1992, *Recommended Practice for Nondestructive Testing Personnel Qualification and Certification*, American Society for Nondestructive Testing, December 1992.

Stainless Steel Handbook, Allegheny Ludlum Steel Corp., Pittsburgh, Penn.

SAFETY ANALYSIS REPORT, Y-12 NATIONAL SECURITY COMPLEX, MODEL ES-3100 PACKAGE WITH BULK HEU CONTENTS

Prepared by the
Oak Ridge Y-12 National Security Complex
Oak Ridge, Tennessee 37831
Managed by
BWXT Y-12 L.L.C.
for the
U. S. Department of Energy
under contract DE-AC05-84OR21400

August 15, 2005

DISCLAIMER

The following contractors, consultants, and companies assisted BWXT Y-12, L.L.C., in the preparation of this Safety Analysis Report:

G2 Engineering and Management, Inc.
Navarro Research & Engineering, Inc.
UT-Battelle

CONTENTS

CONTENTS continued

REVISION LOG

Date	Revision No.	Description	Pages
02/25/05	0	Original issue	All
08/15/05	Page Change 1	Page changes resulting from *Responses to Request for Additional Information* #1, Y/LF-747.	title page, iv, xxiii, 1-4, 1-145, 2-2, 2-3, 2-6, 2-31, 2-32, 2-33, 2-34, 2-57, 2-59, 2-61, 2-107, 2-125, 2-131, 2-171, 2-173, 2-181, 2-183, 2-185, 2-186, 2-189, 2-367, 2-458, 2-675, 8-8, 8-9, 8-31

Mechanical properties

The O-ring material mechanical properties of hardness and elongation shall be determined for each lot. Their acceptance criteria and sensitivity are:

1. hardness of Shore A 70 ± 5 durometer, and

2. elongation of 100%, minimum.

All O-rings in a lot that fail to meet these criteria shall be rejected. If O-rings from a rejected lot have already been used, the licensee shall locate all such O-rings and either examine or discard them. O-rings from a rejected lot that are in a containment vessel that is still loaded shall be removed at the earliest possible time.

8.1.6 Shielding Tests

No gamma or neutron radiation shields are integral to the packaging.

The Cat 277-4 (JS-YMN3-801580-A005, Appendix 1.4.5) liner is specifically designed for criticality safety. Acceptance testing for the Cat 277-4 liner will be described in a testing procedure which includes the following information:

- Description of the measuring technique including the electronics
- The source type and strength used to measure the shield effectiveness
- The standards and methods used to calibrate the source, sensors, and other equipment
- The grid pattern used to check the shield
- The type of neutron sensor used to measure the shield effectiveness
- The specific test requirements and measurements
- The acceptance criteria

8.1.7 Thermal Tests

A thermal acceptance test is not required for this package. The maximum decay heat generated by the radioactive material is 0.4 W (Sect. 1.2.3.7 and 3.1.2), which is negligible. Fabrication of the Kaolite 1600 thermal insulation in accordance with the process specification (Appendix 1.4.4) fulfills the obligation for a thermal acceptance test.

8.1.8 Miscellaneous Tests

Material certification and visual inspection for damage are required for the following packaging components: plastic pieces, washers, tamper-indicating devices (TIDs), and paint. All materials shall be in compliance with the respective material properties and tested when applicable, as stated in their respective specifications. A nonconforming or damaged part is cause for rejection.

To prevent the use of noncertified fasteners, acceptance inspection and tests have been added to ensure their quality. The fastener structural tests include mechanical property tests and chemical tests to ensure that the correct materials were used.

8.2 MAINTENANCE PROGRAM

When the package is being loaded or unloaded, it shall be examined to ensure that all parts are present and functional. A record shall be generated of this examination activity with the affected part numbers, personnel doing the work, and the date of the activity being recorded. This examination activity and the activities associated with the periodic and maintenance leak tests are considered refurbishment activities. Periodic maintenance of the ES-3100 shall be performed on an annual basis, and shall include visual inspections and leak tests. No ES-3100 shall be used unless maintenance documentation reflects the package is current on periodic maintenance. The periodic and maintenance refurbishment requirements are given below.

8.2.1 Structural and Pressure Tests

Structural and/or pressure tests, as identified in Sect. 8.1.3, shall be performed as appropriate for the respective part or component after welding or other structural repairs are made. Welding and structural repairs of the containment vessel involve rework operations and are considered beyond the scope of refurbishment activities.

8.2.2 Leakage Tests

Maintenance and periodic leak tests, as defined by ANSI N14.5-1997, Sects. 7.4 ("Maintenance Leakage Rate Test") and 7.5 ("Periodic Leakage Rate Test"), shall be performed during refurbishment when necessary. The fabrication leakage rate test (Sect. 8.1.4) is performed prior to the package's first use; the package must be retested following repair or replacement of a containment system component (maintenance leakage-rate test) or annually while the package is in use (periodic leakage-rate test). Packages that are not in use and have not had a periodic leakage-rate test within the last 12 months must be tested prior to use.

> Note: Interpretation of the intent of ANSI N14.5-1997, Sect. 7.4, and implementation guidance of the ANSI standard prepared by the certifying organization is that only the preshipment leakage-rate verification (ANSI N14.5-1997, Sect. 7.6) be completed when suspect O-rings are replaced at times other than during the annual package recertification maintenance. This is acceptable for O-rings (such as the ES-3100 O-rings), which are procured, evaluated, and maintained in accordance with Y-12's QA program.

Following the successful completion of the leak tests, two copies of the label shown in Fig. 8.1 shall be filled in and attached to the exterior surface of the containment vessel and the drum. Note that completion of the leak tests recorded on these labels satisfies the requirement that the fabrication leak test be performed before the first use and that periodic leak tests are performed annually thereafter while the package is in use. Packages must be loaded onto the Safe-Secure Trailer/Safeguards Transporter, and DOE must take custody of the package prior to the expiration date for the leak test. The package must arrive at its destination prior to expiration of the CoC.

Maintenance and periodic leak tests shall be performed using the same procedure and with the same acceptance criteria as the fabrication leakage rate test described in Sect. 8.1.4. The maintenance and periodic leak tests performed in the manner described in Y-12 Plant Product Specification Procedure Y51-01-B2-R-140 (Appendix 8.3.1) test the entire containment boundary with an integrated leak rate exceeding 1.9×10^{-7} atm-cm^3/s of helium (or equivalent) as cause for rejection. With successful completion of the test, the entire containment boundary is considered "leaktight." Use of the Y-12 procedure presented in Appendix 8.3.1 is not mandatory; however, the user must ensure that his or her procedure meets the requirements of ANSI N14.5-1997.

If a package does not pass the preshipment leakage-rate test described in Sect. 7.1.2.1 of this Safety Analysis Report, the O-ring sealing surfaces shall be examined. Nicks and scratches of the O-ring groove in the containment vessel flange or sealing surfaces of the containment vessel sealing lid may be smoothed with a stone or with fine sandpaper to return them to specification. Deep scratches are cause for rejection. The O-rings shall be visually examined with the unaided eye for roughness, porosity, or surface defects and will be replaced as necessary. If such actions fail to rectify the inability of the vessel to pass the leak test, further inspection of the containment boundary, including inspection of the welds if present for cracks, may be performed, or the vessel may be permanently rejected. If further work is required for the containment vessel to pass the leak test (such as repair of deep scratches in the O-ring groove or repair of any of the vessel welds), the vessel shall undergo the acceptance tests outlined in Sect. 8.1 prior to reuse.

8.2.3 Component and Material Tests

Since the Kaolite insulation material and Cat 277-4 are encapsulated within the stainless steel liner, no damage or deterioration is expected. The drum assembly and top plug will be weighed prior to first use and during each refurbishment to ensure that there have been no density changes in the Kaolite 1600 or the Cat 277-4. Other components, such as fasteners, O-Rings, etc., are examined and replaced as needed.

8.2.4 Thermal Tests

Because the insulation is not accessible, visual examination is not required. However, the drum, liner, internal flange, flat cover, and top plug shall all be visually inspected for tears or punctures or other defects that would allow for the escape of crushed insulating material.

8.2.5 Miscellaneous Tests

8.2.5.1 Visual Inspection for Corrosion

The ES-3100 package will be stored in controlled indoor facilities; thus, surface corrosion is not expected. However, before each use and during annual inspections, all surfaces shall be visually inspected for corrosion (rust). The observation of surface rust on any component will be cause for further inspection. If the rust can be easily wiped off and no pitting is apparent beneath it, the package is acceptable for use. If the rust cannot be easily wiped off, if scaling is present, or if pitting is observed, the component must undergo dye-penetrant and radiographic testing to determine the extent of the damage before the package can be used.

8.2.5.2 Visual Inspection of Containment Vessel

The containment vessel lid must be removed before performing maintenance or periodic visual inspections on the containment vessel.

The containment vessel surfaces shall be examined for moisture. Water could enter the containment vessel due to improper assembly, defective O-rings, scratches on the O-ring groove or sealing surfaces, or through cracks in welds. Any containment vessel exhibiting signs of water inside will be tagged and segregated until the cause is determined and corrected and the containment vessel has been successfully reinspected.

8.2.5.3 Subsystem Maintenance

Defects in the drum (tears, broken welds, or dents >1-in. deep) are cause for rejection. Failure of the drum seam weld or bottom end-to-body weld shall be recorded as a failure and compared to others. If a statistically significant quantity of drum-weld failures from a single lot exist, then all drums from that lot

shall be examined for weld failures. Those with failures shall be repaired; those without failures shall be released for use.

Touch-up paint for cosmetic purposes may be applied to the markings.

The data plates shall be visually examined. The ES-3100 data plate shall contain the appropriate certification numbers and shall be welded to the drum surface. All surfaces of the drum body shall be visually inspected for moisture prior to content loading, during preparation of empty packages for shipment and storage, and during maintenance activities.

8.2.5.4 Fastener Inspection

The Y-12 Procurement Organization verifies that all fasteners received for use are certified and that they meet the requirements identified in the procurement specifications. During refurbishment of the ES-3100 package, the operators shall verify that the original fasteners are still with the package. This is done by inspecting the fasteners to determine if they have the proper certification markings. If there is any question about the certification status of the fasteners, all the fasteners shall be replaced.

Containment vessel lid assembly fasteners (closure nut and retaining ring) and the drum lid fasteners (5/8-in.-11UNC bronze hex nuts) shall be visually inspected during all routine maintenance activities and pre-use inspections. Fasteners with damaged threads (evidence of cross-threading or flattened threads) or excessive wear (visually apparent rounding of the fastener threads) must be replaced with certified replacements. Fastener replacement will be documented in the package's maintenance records.

8.2.5.5 Valves, Rupture Disks, and Gaskets on Containment Vessel

The O-rings are visually inspected for defects such as roughness, porosity, and outer surface defects. Defective O-rings are discarded. Each time a containment vessel is refurbished, the containment boundary (including the O-rings) is checked for sealing ability. See Sect. 8.2.2 for the requirements of the leak test of the containment boundary during refurbishment.

All O-rings in use will be replaced annually. Furthermore, new O-rings, which are stored in sealed containers, will not be stored for more than four years from the date of manufacture. Thus, no O-rings will be used that have been manufactured more than five years prior to the date of last use.

There are no valves or rupture disks in the packaging.

8.2.5.6 Miscellaneous

The drum assembly and top plug will be weighed prior to first use and during each refurbishment to ensure that there have been no density changes in the Kaolite 1600 or the Cat 277-4. Weights will be compared to the weights prior to first use, and the drum assembly or top plug will be rejected and evaluated for rework if the weight change is >3 lb.

The silicone rubber pads shall be inspected during the annual recertification maintenance to verify that there are:

1. no pad swellings due to moisture absorption;
2. no gouges, cuts, tears, or nondesign voids in the pads;
3. no unauthorized modifications to the pads; and
4. no substitutions of pads with unauthorized replacements.

Distribution:

J. C. Anderson
J. G. Arbital, G2 Engineering and Management, Inc.
P. A. Bales
G. A. Byington
J. F. DeClue
B. G. Eddy, NNSA/YSO
M. R. Feldman, UT-Battelle
M. L. Goins
M. E. Hassler
A. Janasi, Knolls Atomic Power Laboratory
R. Koenig, Savannah River Site
P. T. Mann, DOE-NA-124
T. D. Pflaum, DOE-NA-131
J. W. Pugh, Nuclear Fuel Services, Inc.
E. D. Ragos, NNSA/YSO
J. M. Shuler, DOE-EM-24
S. A. Thompson, DOE/OST
D. R. Tousley, DOE-NA-261
T. L. Warren – RMR
S. A. Williams, U.S. Nuclear Regulatory Commission (10)
S. J. Williams, BWXT Lynchburg
HDPO DMC
Y-12 Central Files – Record Copy, Attn: Dale D. Wilson

BWXT Y-12

Protecting America's Future

Y-12 NATIONAL SECURITY COMPLEX

Y/LF-747

RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION #1
Docket No. 71-9315
TAC No. L23818

on the

Safety Analysis Report,
Y-12 National Security Complex,
Model ES-3100 Package with Bulk HEU Contents
(Y/LF-717, Rev. 0, February 25, 2005)

BWXT Y-12, L.L.C.

August 15, 2005

MANAGED BY
BWXT Y-12, L.L.C.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-13672 (11-03)

Y/LF-747

RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION #1

on the

Safety Analysis Report, Y-12 National Security Complex,
Model ES-3100 Package with Bulk HEU Contents (Y/LF-717, Rev. 0, February 25, 2005)

August 15, 2005

Prepared by the
Y-12 National Security Complex
Oak Ridge, Tennessee 37831

Managed by
BWXT Y-12, L.L.C.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

1.0 General Information

1-1 The text on page 1-4 states, "By certifying that the drums used in production meet the same specifications as those in the compliance tests specified in 10 CFR 71." Provide justification that this statement is valid given that the production drums are by default not built to the same specifications as the drums tested for compliance due to the change in the neutron absorber.

Applicant Response:

The drum referred to in this statement is the outer shell of the ES-3100 Drum Assembly, not the entire assembly with the inner liner, kaolite, and neutron absorber. This will be clarified in the SAR.

In the SAR, the last sentence of the second paragraph of Sect. 1.2.1.1 will be revised to read as follows:

"By certifying that the outer shell of the Drum Assembly used in production meets the same specifications as those tested and analyzed, as described in subsequent sections of this SAR, the outer drum shell used for the ES-3100 is acceptable for a Category 1 shipping package."

1-2 Assess the statement on page 1-145, Appendix 1.4.6, "this package is classified in Table 2.2 of NUREG-1609 as a Category II package."

There is no Table 2.2 in NUREG-1609, as referenced.

Applicant Response:

This was a reference error. Table 1.1 should have been referenced here. In the SAR, the references to NUREG-1609 Table 2.2 in the last sentence of Appendix 1.4.6 and in the second sentence of the first paragraph of Sect. 2.1.2.2 will be changed to Table 1.1.

2.0 Structural

2-1 Provide consistent wording when using confinement and containment. Be consistent in wording when conveying the same conclusion in different sections. Revise as appropriate.

Applicant Response:

The applicant agrees with this comment. Use of the word "confinement" will be modified for consistency. The following changes to the SAR will be made:

In the SAR, the ninth sentence in Sect. 2.7.1.3, the ninth sentence in Sect. 2.7.1.4.1, and the eighth sentence in Sect. 2.7.1.4.2 will be revised as follows:

"The lid was still firmly attached to the drum assembly, with no visible separations or rips; thus, the position of the containment vessel inside the drum (and therefore the contents of the shipping container) was maintained."

2-2 Provide the correct range in the last sentence on page 2-131, "The range is zero to *5,175* psi and the alternating stress is half of the range or *5,147* psi / 2 = 2,574 psi."

The range is either 5,175 psi or 5,147 psi.

Applicant Response:

This was a typographical error that was not corrected during internal review. The correct upper end of the range is 5,147 psi. In the SAR, the last sentence in the second paragraph of Sect. 4.4 on page 2-131 of Appendix 2.10.1 will be revised to reflect 5,147 psi instead of 5,175 psi.

2-3 Use the same hardening exponent label throughout the application and correct its definition.

The strain hardening equation on page 2-181 labels the hardening exponent with the letter "m." The power law equations on pages 2-181, 2-183, and 2-185 labels the hardening exponent as epsilon (ϵ). Also, the hardening exponent is incorrectly defined as the "hardening coefficient."

Applicant Response:

The applicant agrees. The "hardening coefficient" should have been noted as the "hardening exponent." In the SAR, the text "ϵ = hardening coefficient" will be changed to "m = hardening exponent" in the following three locations:

1) near the bottom of p. 2-181
2) near the middle of p. 2-183
3) near the bottom of p. 2-185

2-4 Figure 2.3.5.1 (page 2-186), Table 2.3.5.1.1 (page 2-187), Table 2.3.5.2.1 (page 2-188), and Table 2.3.5.3.1 (page 2-190) reference uniaxial strain. To be consistent with the test report, the text should reflect that constrained Kaolite material data is the same for uniaxial and volumetric strain.

Applicant Response:

The applicant agrees with the reviewer. For these specimens, volumetric and uniaxial strain data are the same. For clarification in the SAR, the following text will be added after the last sentence in Sect. 2.3.5 on page 2-186:

"The Kaolite test data was obtained from constrained test specimens. For the constrained Kaolite test data, the material data is the same for uniaxial and volumetric strain."

2-5 The text on page 2-189, second to last line reads "a density of 27 lb/ft^3 is used as in the low density run." This sentence should read "a density of 27 lb/ft^3 is used as in the low stiffness run."

Applicant Response:

The applicant agrees. The next to last sentence on p. 2-189 will be revised to change the word "density" to "stiffness."

2-6 Justify the circumstances that exempt the weld studs from having a Certified Material Test Report on file as noted on page 1-69.

Applicant Response:

Justification for not requiring a Certified Material Test Report for the drum lid studs is provided by the guidance given in NUREG/CR-3854. NUREG/CR-3854, Sect. 4.2, Table 4.1 Note 6, Components used for secondary bolts in Category I, other safety groups, states:

> "Criteria from equivalent ASTM materials and standards, DOT specifications or articles in ASME Code Section III, Subsection NF may also be substituted, all or in part."

As shown in Table 2.13 of the SAR, the raw material used for the studs meets the requirements of ASTM A-493 and the studs are produced in accordance with ASTM F593. During receipt of production units of the ES-3100, the procurement department of BWXT Y-12 will require a Certificate of Compliance from the fabricator to be included. In ASTM F593, Item 17.1, Certificate of Compliance, it is stated that unless otherwise specified in the purchase order, the manufacturer shall furnish certification that the product was manufactured and tested in accordance with this specification and the customer's order, and conforms to all specified requirements. This certification is the substitute of a Certified Material Report as allowed by NUREG/CR-3854.

2-7 Provide an explanation as to which of the statements below is correct and revise as necessary.

The text on page 1-5 states that "No tie-down devices are integral to the package, nor can any features be used for these purposes." Page 2-2 states, "This [welded angle ring] was incorporated in the ES-3100 package for use during transport to facilitate tie-down as a single unit in the Safe-Secure Trailer/Safeguards Transporter (SST/SGT)..."

This information is required to determine compliance with 10 CFR 71.7 and 10 CFR 71.45.

Applicant Response:

The text on page 1-5 is correct, as it is the intent of this package to not include any integral tie-down devices. The text on page 2-2 did not thoroughly explain the situation with regard to the function of the welded angle ring and single unit tie down in the transporter. The ring is not functional as a tie-down device. For clarification, the nineteenth sentence of the second paragraph of Sect. 2.1.1.1 (sentence beginning with, "This was incorporated ...") will be replaced with the following two sentences:

"The welded angle ring was incorporated in the ES-3100 package for use during handling and transport to protect the lid closure studs and nuts. During transport, the welded angle ring helps position drum tie-down adapters that are used for tie-down of a single unit configuration in Safe-Secure Trailers/Safeguards Transporters (SSTs/SGTs) in accordance with U.S. Department of Energy (DOE) Order 5610.14."

The lack of integral tie-down devices on the ES-3100 is also covered in Section 2.4.2 of the SAR.

2-8 Provide information regarding the tie down arrangement for the package(s) and include any stress calculations that demonstrate the package can withstand any tie down forces that may act on a structural component integral to the package.

No explicit information is given for the tie-down arrangement.

This information is required to determine compliance with 10 CFR 71.7 and 10 CFR 71.45.

Applicant Response:

The tie-down arrangement for the ES-3100 package will be detailed in the Technical Manual, *Tiedown Procedures for Type -B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)* by K. J. Padilla, January, 2004. This manual is produced by Sandia National Laboratory in support of the DOE Transportation Safeguards System. An actual entry for the ES-3100 has not yet been added to the manual, but this will be completed prior to first use of the package. As an example of the information that will be provided in the Tiedown Manual for the ES-3100, the entry for the DOT 6M-55 can be reviewed. The manual shows 6M tie-down arrangements for a single unit tie-down and for tie-down of multiple packages in a Cargo Restraint Transporter. This manual is U.S. Department of Energy "Official Use Only."

For further clarification of the tie-down system, the "Analysis" section of Sect. 2.4.2 will be replaced with the following text:

"The ES-3100 package, as delivered for transport, has no tie-down devices that are structural parts of the package. Therefore, the tie-down requirements of 10 CFR 71.45 are not applicable.

Safe tie down and transport of the package is accomplished by two methods explained in *Tiedown Procedures for Type B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*, rev. 5 (Padilla 2004). Method one, shown in Sect. 3.4 of Padilla 2004, is for single-unit tie-down. A drum tie-down adapter is positioned on top of the drum and two chains, passing through the adapter, are attached to equipment positioned on the floor of the transport vehicle. The welded ring on the drum lid helps to initially position this drum tie-down adapter as well as prevent inadvertent assembly damage to the studs and nuts. The second method of securing the ES-3100 package is by the use of the Cargo-Restraint Transporter (CRT) (Padilla 2004, Sect. 6). In this method, a frame is positioned around the base and top of either four, five, or eight packages. These frames are then chained to the floor as depicted in Fig. 6-3 of Padilla 2004. Tension is applied to the chains to eliminate any slack in both methods. The downward load resulting from the chain tensioning is insignificant when compared to the compression loading specified in 10 CFR 71.71(c)(9)."

The following reference will be added to Sect. 2:

Padilla, K. J., *Tiedown Procedures for Type-B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*, rev. 5, Sandia Natl. Labs., Albuquerque, NM, Jan. 15, 2004. OFFICIAL USE ONLY.

2-9 **Demonstrate that the TID lugs cannot be used for a tie-down location that is integral to the package.**

This information is required to determine compliance with 10 CFR 71.7 and 10 CFR 71.45.

Applicant Response:

Administrative controls are used with strict adherence to procedures documented in *Tiedown Procedures for Type B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)* by K. J. Padilla, January 2004. The TID lugs are not used for tie down purposes shown for any tie-down method. Methods for securing the ES-3100 package will be incorporated into Padilla 2004 prior to initiation of ES-3100 shipping campaigns.

2-10 **Provide relevant details regarding what cases and under what circumstances the modeling techniques utilized are valid.**

In three locations in the SAR, the use of the language "has been historically used" (pages 2-173, 2-186), and "has historically shown" (page 2-183), is insufficient to make a determination of fact regarding the adopted FEA modeling approaches.

Applicant Response:

Modeling techniques such as used on the ES-3100 have been used on other packages licensed by DOE NNSA to 10 CFR 71 requirements. For clarification in the ES-3100 SAR, the phrases including "historically" will be revised as specified here.

The last sentence on page 2-173 will be revised as follows:

"This modeling approach has been used and accepted for NNSA-licensed shipping packages that where subject to independent review and verification analysis (i.e., DPP-2 and ES-2100)."

The last sentence on page 2-183 will be replaced with the following text:

"The modeling of the drum studs with engineering stress/strain data curve is conservative from a design standpoint. This approach has been used and accepted for NNSA-licensed shipping packages that where subject to independent review and verification analysis (i.e., DT-22 and DT-23)."

The second sentence on p. 2-186 will be revised as follows:

"The LS-DYNA honeycomb material model (*MAT_HONEYCOMB) used for the ES-3100 has been shown to be a good representation of the Kaolite material and approved for NNSA-licensed shipping packages that where subject to independent review and verification analysis (i.e., DPP-2 and ES-2100)."

2-11 Justify the use of LS-DYNA material *MAT_SOIL_FOAM for modeling the Borobond and Cat 277-4 material (HABC).

Given that compressive strength material properties were obtained using ASTM C109-02 *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars* and that reported material properties are more representative of lightweight concrete rather than soil or foam, it is unclear as to why a concrete material model was not used for the Borobond and Cat 277-4 (HABC).

Applicant Response:

LS-DYNA material type 5 (*MAT_SOIL_AND_FOAM) is a simple, older material model in LS-DYNA that can be used to model concrete. From the LS-DYNA theoretical manual, the paper that is the basis for material type 5 is *A Simple Constitutive Description for Cellular Concrete* by Krieg (1972). Also, "Material models 5, 14, 16, 25, 72, 96, 84 and, in Version 970 of the code, material 145, can be used to model concrete with solid elements." (From reference: http://www.dynasupport.com/Support/howto/concrete.models).

The Borobond material model used in the ES-3100, material type 5, was chosen based on previous experience/analytical work as described below. When the material was changed from Borobond to HABC (Cat 277-4), material type 5 was chosen to model the HABC material since it was also a concrete type material. Because the Borobond design of the ES-3100 was tested, it was desired to minimize the changes between the Borobond and HABC analytical models.

The LS-DYNA material type 5 model described on p. 2-191 of the SAR for the ES-3100 Borobond material is the same material model that was used in an on-site storage container, the rackable can storage box (RCSB). The RCSB is a 4-ft long by 3-ft wide by 1.5-ft high, 304 stainless steel lined (0.075 in. plate) box filled with the Borobond material (minus six, seven-inch cylindrical cavities). The RCSB weighs about 1809 lb total, with 1189 lb being the Borobond material. The RCSB was dropped from a height of 28 ft onto a rigid surface. The analytical results compared favorably with the test results as shown below.

Figure 1 shows an initial view of the RCSB for a 12-degree slapdown onto the lid. The lid of the storage pallet is facing the rigid surface and the bottom forklift region of the pallet is in view. Figures 2 and 3 show the analysis and test results for the slapdown impact. The initially impacting lid edge is shown to the right in Figs. 2 and 3, and the subsequent secondary impacting end is to the left.

Figure 4 shows the initial configuration of the corner edge impact. Figures 5 and 6 show the results for a corner edge impact of the RCSB. Figure 5 shows the analytical results of the corner impact. Figure 6 shows the test final configuration for the corner impact.

No changes to the SAR are suggested in response to this comment.

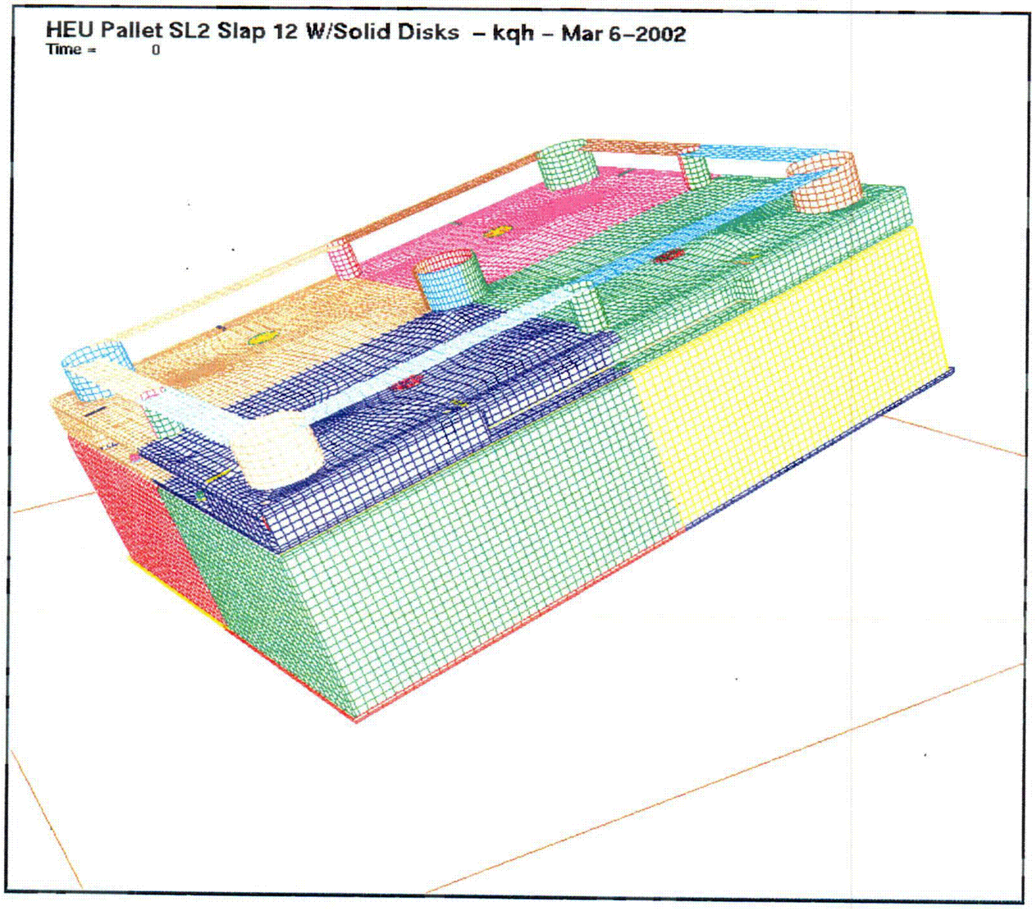

Fig. 1. Initial configuration of the 12-degree slapdown impact.

C04

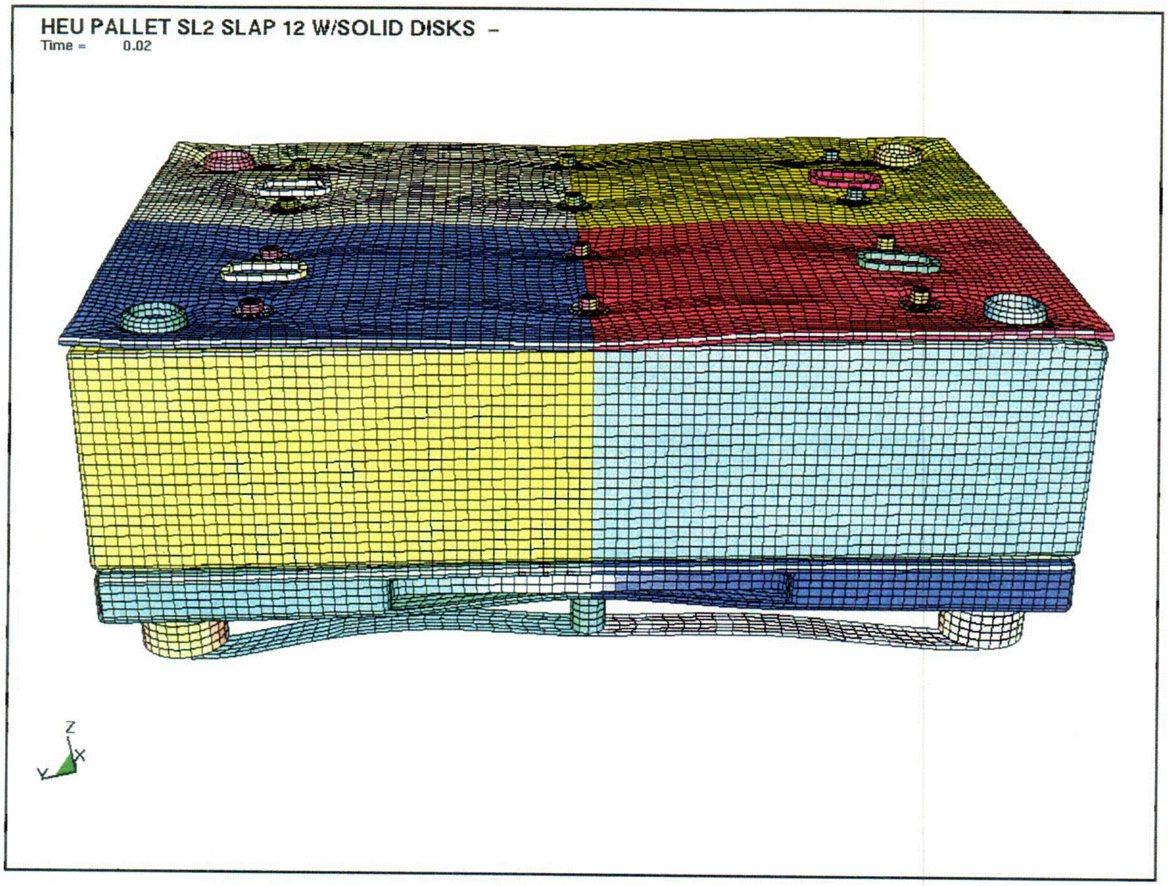

Fig. 2. Configuration of the RCSB package on th impacting top.

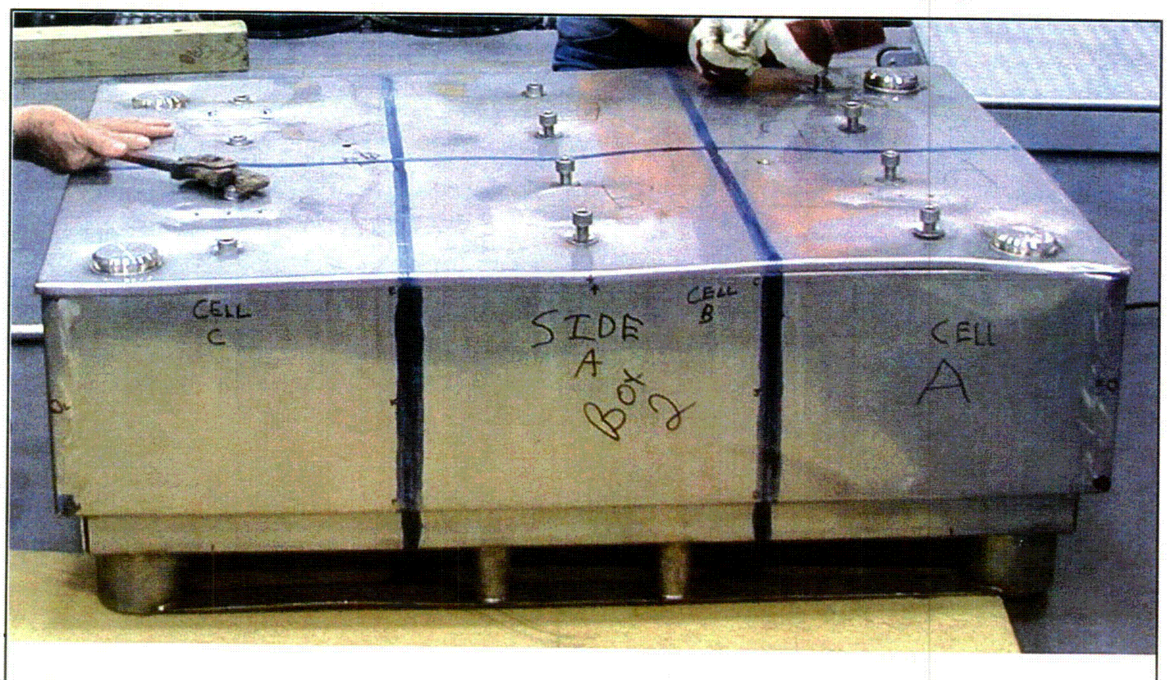

Fig. 3. Configuration of the RCSB after the slapdown test.

C05

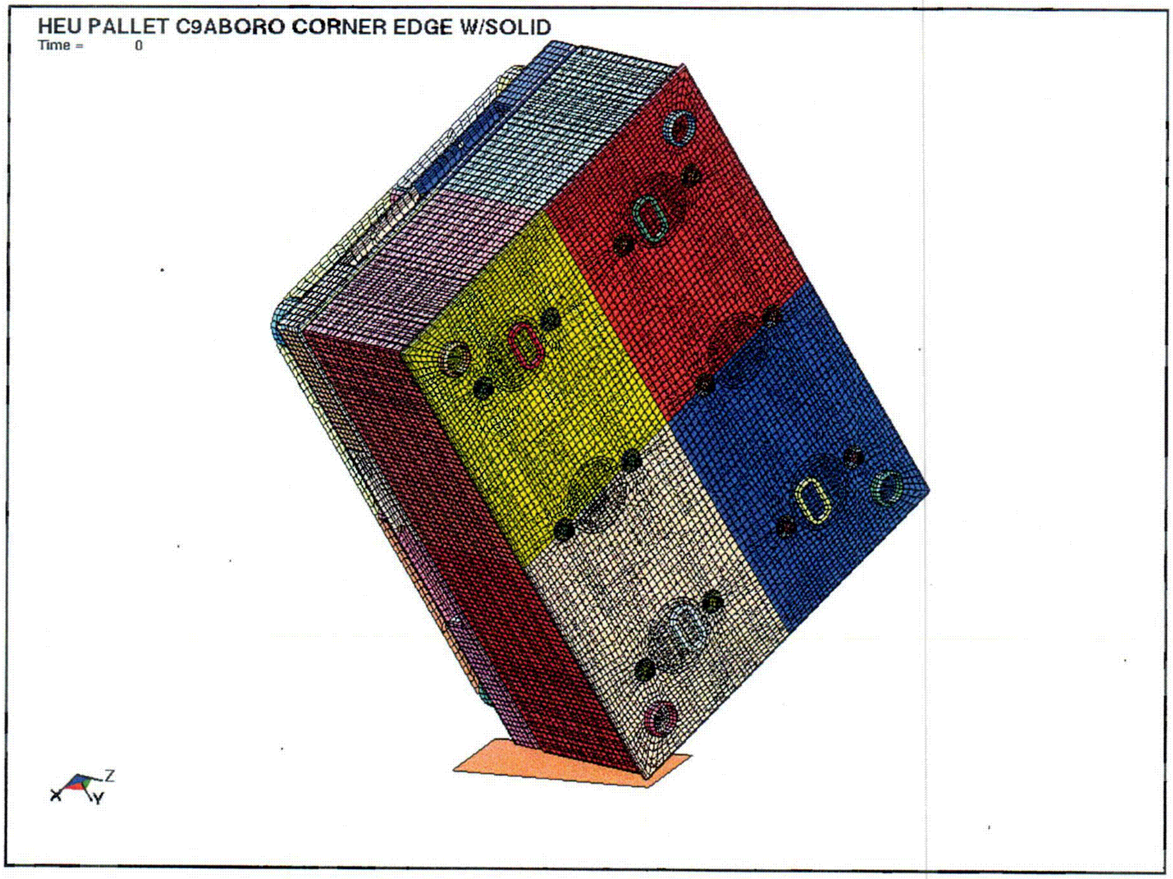

Fig. 4. RCSB corner impact initial configuration.

C06

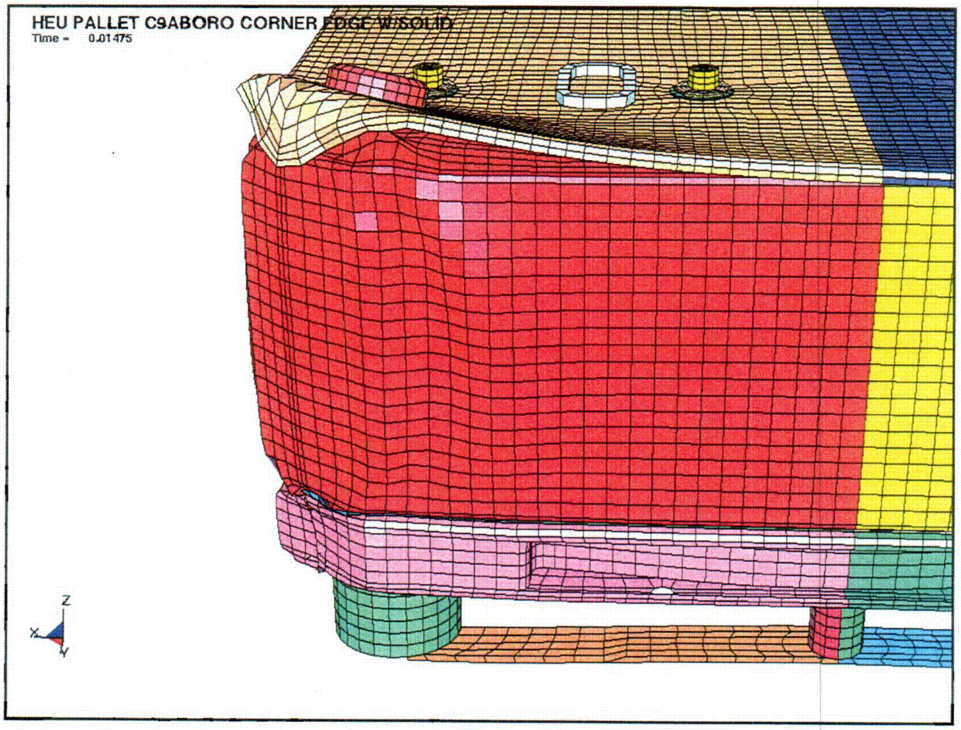

Fig. 5. Configuration of the impacted corner.

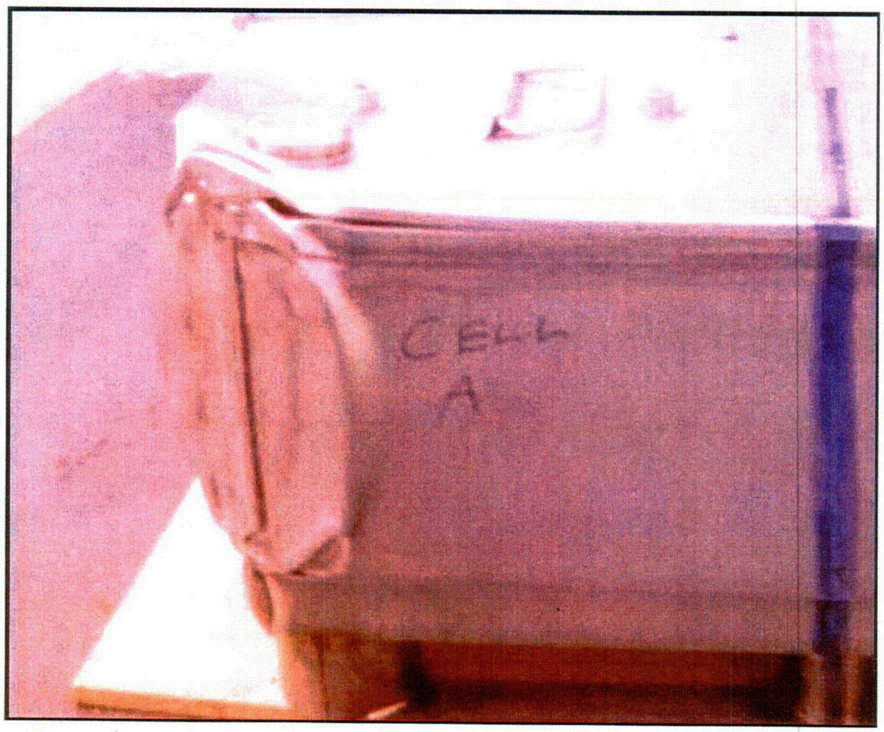

Fig. 6. Final configuration after the test.

C07

2-12 **Provide an example calculation and source used to derive the pressure vs. volumetric strain relationship from the uniaxial strain information for Cat 277-4 (HABC). Specifically address how the coefficient, mu (μ) was derived, where mu is the ratio of lateral strain to longitudinal strain.**

Given that volumetric stress strain data is lacking, a full methodology along with assumptions and sample calculations is necessary for determining if the derivation is appropriate.

Applicant Response:

The derivation of the HABC volumetric properties is outlined on pages 2-366 through 2-368 of the SAR. The following detailed calculation is applicable to the -40°F HABC material data and uses the formulas outlined on those pages. Similar calculations were performed for the 70°F (page 2-368) and the 100°F (page 2-369) cases, but are not included in this detailed derivation.

The test data in Table 1 was obtained from Y-12 report Y/DW-1987, *Mechanical Properties of 277-4*. Table 9 on page 6 of Y/DW-1987 gives the following stress-strain curve for the upper bound of the HABC material (at -40°F).

Table 1. Upper bound stress-strain curve - test data points

Strain x 10^6 (in./in.)	Stress (psi)
0	0
101.1	201.3
251.8	378.8
390.9	561.9
579.6	721.1
762.8	883.1
1002.9	1017.6
1305.2	1122.2
1663.2	1200.1
2108.4	1236.1
2600	1249.7

Table 11, page 6 of Y/DW-1987 gives the poisson's ratio as 0.33 for -40°F.

The modulus of elasticity was taken to be the slope of the load deflection curve for the first data point.

$$E = \frac{\sigma}{\epsilon} = \frac{201.3 - 0}{(101.1 \times 10^{-6}) - 0} = 1.991 \times 10^{6} psi$$

The shear modulus is then calculated as:

$$ShearModulus = \frac{E}{2(1+\nu)} = \frac{1.991\times10^6}{2(1+0.33)} = 7.485\times10^5 psi$$

The bulk modulus is calculated as:

$$BulkModulus = \frac{E}{3(1-2\nu)} = \frac{1.991\times10^6}{3[1-2(0.33)]} = 1.952\times10^6\ psi$$

The volumetric strain on page 2-367 of the SAR is shown to be:

$$volumetric\ strain = ln\ V = ln\ [\ (1\ -\ \varepsilon_{long})(1\ +\ \mu\varepsilon_{long})^2]$$

The mu (μ) in this equation is Poisson's ratio and should be the symbol nu (ν). This symbol will be changed in the SAR.

Therefore the volumetric strain for the first test data point in Table 1 becomes:

$$volumetric\ strain = ln\ V = ln\ [\ (1\ -\ 0.0)(1\ +0.0)^2] = 0.0$$

The volumetric strain for the second test data point becomes:

$$volumetric\ strain = ln\ V = ln\ [\ (1\ -\ 101.1\times10^{-6})(1+0.33*101.1\times10^{-6})^2]$$
$$= -3.4380\times10^{-5}\ in./in.$$

In similar manner, the subsequent test data is converted to volumetric strain. Using $P = \sigma/3$, the pressure for the first data point is P = 0.0/3 = 0.0 psi. The second data point becomes P = 201.3 psi / 3 = 67.1 psi. The subsequent data points are determined in a similar manner. The resulting volumetric strain data versus pressure curve is given in Table 2 and shown graphically in Fig. 1.

Table 2. **Upper bound load-deflection data - test data points**

Strain x 10^6 (in./in.)	Stress (psi)	Volumetric Stain (in.^{3}/in.^{3})	Pressure (psi)
0	0	0	0
101.1	201.3	-0.000034	67.1
251.8	378.8	-0.000086	126.267
390.9	561.9	-0.000133	187.3
579.6	721.1	-0.0001973	240.367
762.8	883.1	-0.0002597	294.367
1002.9	1017.6	-0.0003416	339.2
1305.2	1122.2	-0.0004448	374.067
1663.2	1200.1	-0.0005672	400.033
2108.4	1236.1	-0.0007196	412.033
2600	1249.7	-0.0008881	416.567

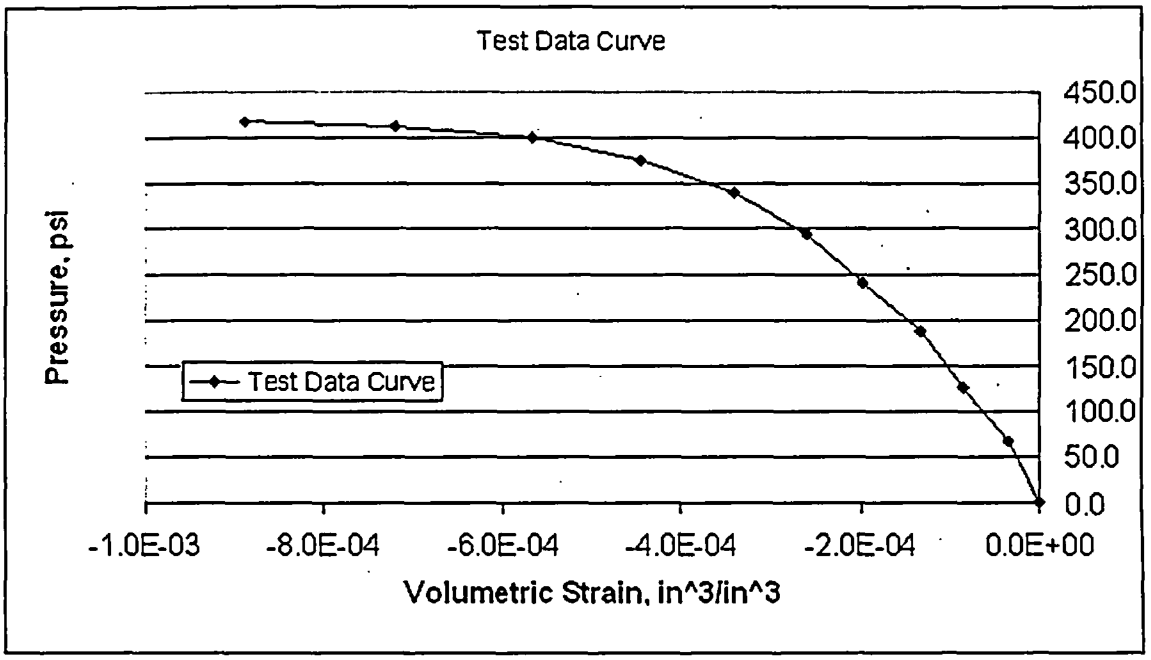

Fig. 1. Test data volumetric strain vs. pressure.

Experience has shown that most of the demand placed on the energy-absorbing material will be within the test data range (verified below). It is also known that LS-DYNA does not extrapolate a material curve. If the solution reaches an undefined region of the material model, then the solution will become unstable and stop. User-defined material data points must envelop any possible strain that could be experienced in any part of the material during the run. Therefore, a transition from the above data set to a relatively high final data point (knowingly to envelop any possible volumetric strain/pressure demand) is assumed. There is no supporting test data for this region, the points are all chosen to give a relatively smooth curve to the assumed final point.

The following data points were assumed and provide a data point envelope for the analytical run. The data points in Table 3 were chosen (assumed) based on providing a relatively smooth curve to a maximum enveloping value. The value at a strain of 0.8 in./in. was assumed and the other points were chosen to give a smooth transition from the test data to the assumed maximum. The Table 2 test data and the Table 3 assumed data make up the full range of data to be used in the LS-DYNA material model. Due to the extreme range of the data, the Table 2 and Table 3 data are plotted in two ranges. Figure 2 shows volumetric strain between -0.4 in^3/in^3 and 0.0. Figure 3 shows the volumetric strain between -1.2 $in.^3/in.^3$ and 0.0.

Table 3. Upper bound load-deflection data - assumed data points

Strain (in./in.)	Stress (psi)	Volumetric Strain (in^3/in^3)	Pressure (psi)
0.01	1300	-0.0034612	433.333
0.1	1500	-0.040426	500.000
0.3	1700	-0.16787	566.667
0.5	1900	-0.38771	633.333
0.6	3000	-0.55498	1000
0.7	30000	-0.78832	10000
0.8	300000	-1.1409	100000

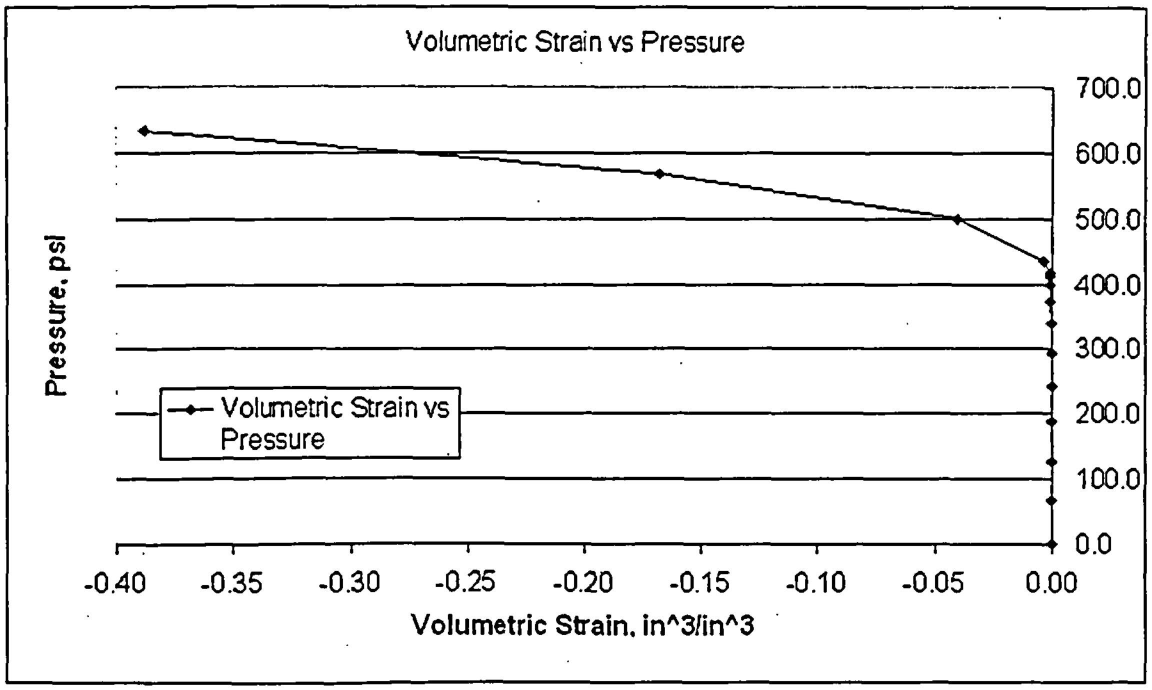

Fig 2. Volumetric strain vs. pressure, -0.4 to 0.0 strain.

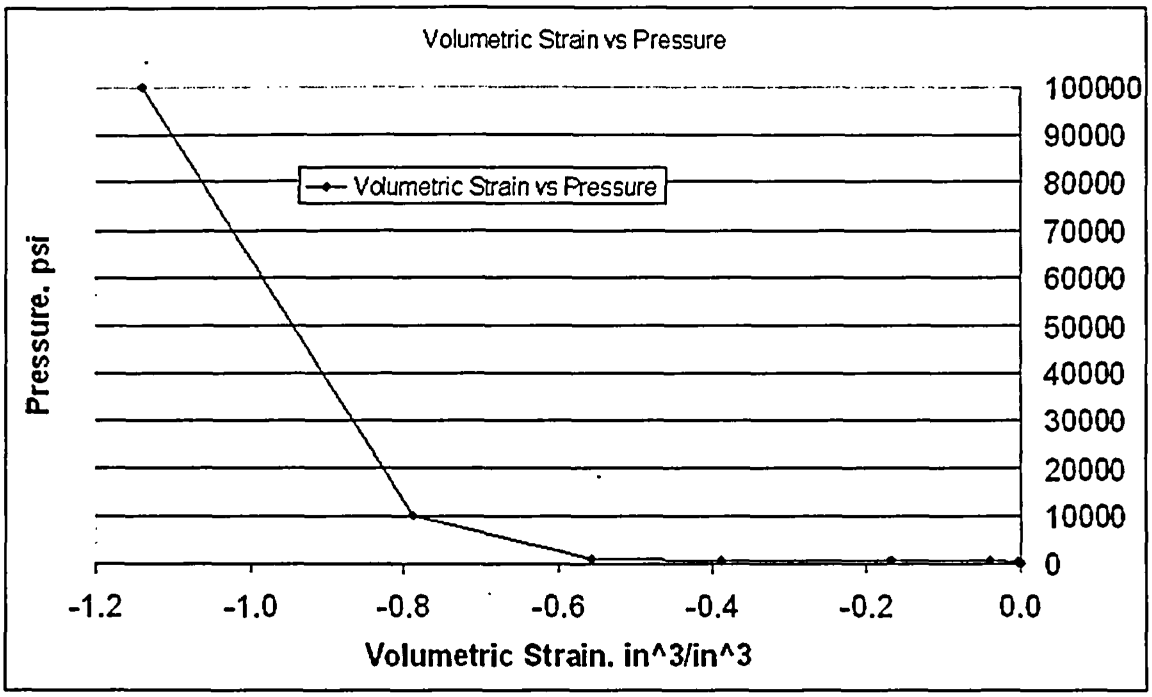

Fig. 3. Volumetric strain vs. pressure, -1.2 to 0.0 strain.

The LS-DYNA material type 5 allows up to 10 data points to define the material curve. Therefore, the data points shown in Table 4 were chosen from the Table 2 and Table 3 data for input to the LS-DYNA model. Figure 4 shows the comparison of the test data curve and the points chosen to be in the LS-DYNA model.

Table 4. Data points for LS-DYNA model

Volumetric Stain ($in.^3/in.^3$)	Pressure (psi)	Origin
0	0	Test
-0.000034	67.1	Test
-0.000133	187.3	Test
-0.0002597	294.367	Test
-0.0004448	374.067	Test
-0.0008881	416.567	Test
-0.0034612	433.333	Assumed
-0.16787	566.667	Assumed
-0.55498	1000	Assumed
-1.1409	100000	Assumed

The tensile strength was obtained from Y-12 report Y/DW-1987, Table 6, page 4 for the upper bound (-40°F). The average value is 234.7 psi. The pressure cut off for the material model is:

$$P = \frac{\sigma}{3} = \frac{234.7\ psi}{3} = 78.2\ psi$$

This is to be entered as a negative number in LS-DYNA, since tension is negative pressure.

The constants a_0, a_1, and a_2 are yield function constants defined in the material model. The pressure dependence of the yield strength is eliminated by setting $a_1 = a_2 = 0$. The compressive strength is obtained from Y/DW-1987, Table 3, page 3 as 1165.8 psi (average). The a_0 term then becomes:

$$a_0 = \frac{\sigma_y^2}{3} = \frac{(1165.8)^2}{3} = 4.53 \times 10^5 psi^2$$

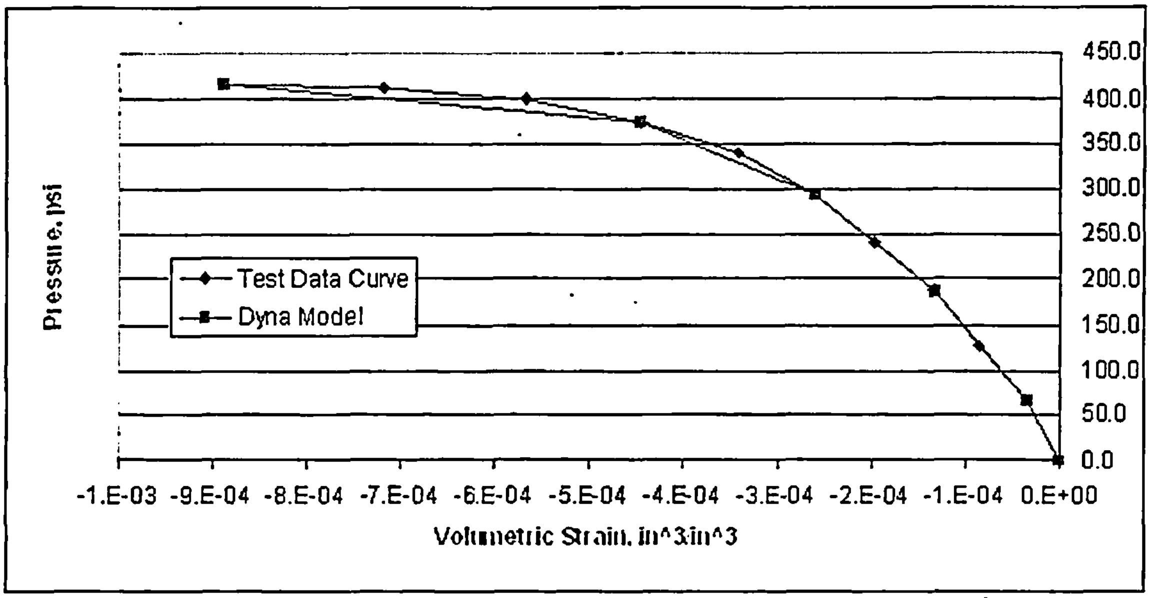

Fig. 4. Data points in the test data range.

As a verification of the fact that most of the strain associated with the HABC material is within the tested data range, and not in the assumed range, the maximum level of pressure in the HABC material is investigated. The HABCrun4g response is chosen due to the fact that it is a slapdown impact with secondary impact on the drum lid end and the crush occurs at the lid end, thereby elevating the demand on the top end of the HABC material. Review of various HABC element pressure time histories and fringe plots of pressure at various times during the impact shows that Fig. 5 is representative of the maximum pressure seen in the HABC material. The maximum magnitude of pressure reached at 0.0332 seconds is shown to be about 505 psi. In the figure, the pressure range has been adjusted such that any color of red in the figure is representative of pressures in excess of the test data range (>416.6 psi). The plot shows that the regions at these levels of pressure are localized at the inner radius of the upper end of the HABC material. Therefore, the effect of the assumed data points is minimal and would not affect the overall model response significantly.

As a result of this comment, the following SAR changes will be made:

The "μ" (mu) used in four places on page 2-367 of the SAR will be changed to the correct symbol "ν" (nu).

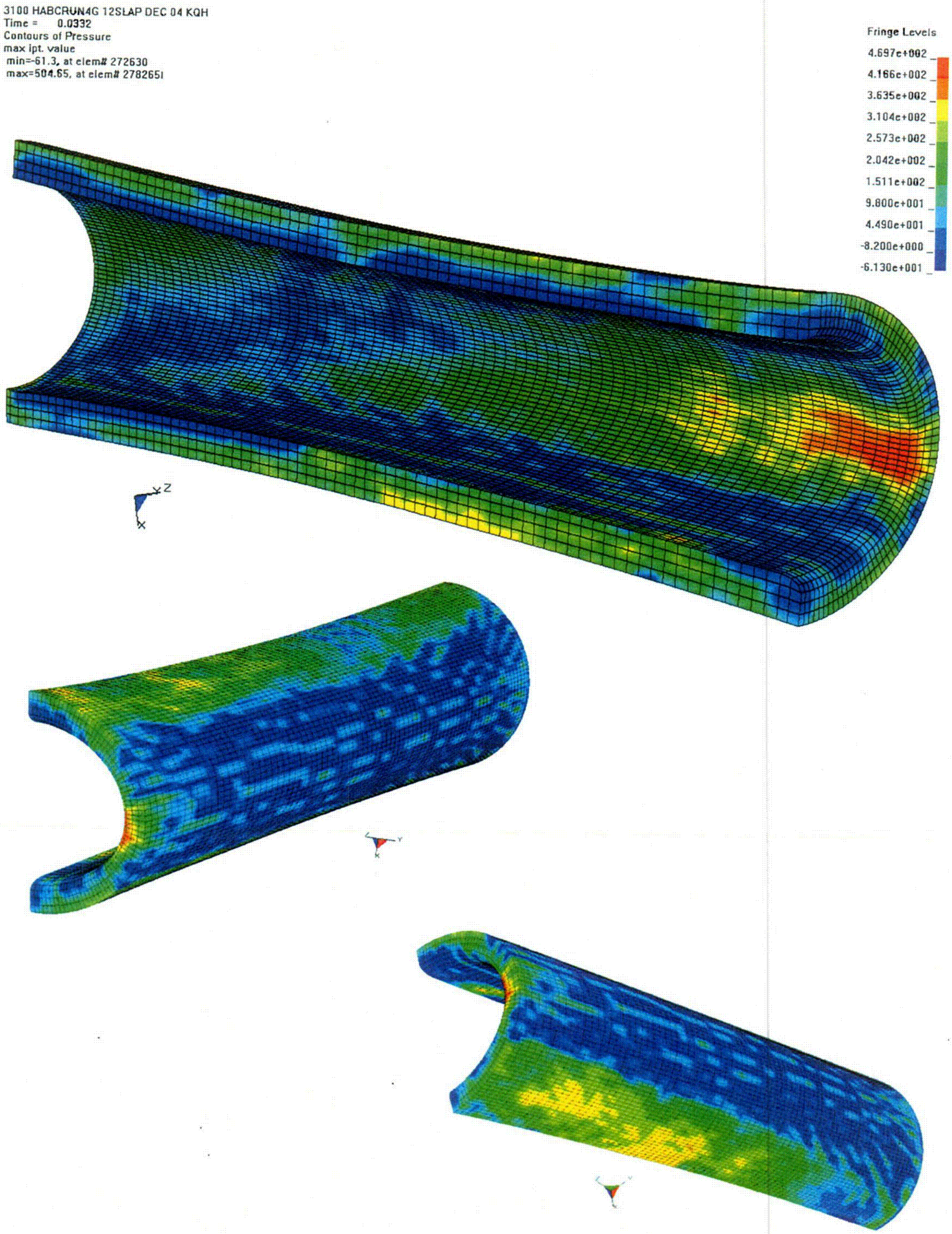

Fig. 5. Pressure in the HABC material at 0.0332 seconds.

C08

2-13 Provide methodology and justification for the extrapolation beyond 0.6 volumetric strain for the Kaolite 1600 material.

It is unclear what procedures were used to extrapolate the stress strain curve for the Kaolite material. Test reports indicate that a sixth order polynomial was used, however, the basis and formulation of this technique was insufficient.

Applicant Response:

The methodology used for the extrapolation of the Kaolite data above the test range is similar in nature to that explained in the response to RAI 2-12. LS-DYNA will not extrapolate material data curves. If the end of the material data curve is reached in a solution, the solution will be stopped due to an instability. Therefore, a "lock-up" point (point at which all voids have collapsed) or an extreme point needs to be defined before the solution is started. This point and the transition from the test data to this point are assumed data points (not supported by test data). In general, the Kaolite state of strain throughout the 10 CRF 71 required impacts is within the test data region (i.e., the "lock-up" point is not reached). The regions of Kaolite which exceed the test data in the solution are typically very localized and occur at corners or localized regions. The HABCrun4g response is chosen to demonstrate this point due to the fact that it is a slapdown impact with secondary impact on the drum lid end and the crush occurs at the lid end, thereby tending to elevate the compressive demand on the Kaolite at the lid end. Figure 1 shows the strain for the Kaolite drum material and the plug. The data range has been adjusted such that strains in excess of the test data range are shown in red (1 - 0.6 = 0.4). It can be seen that most of the Kaolite experiences volumetric strains less than 0.6 in./in. (or, greater than 0.4 in Fig. 1), which is the test data range.

No changes to the SAR are suggested in response to this comment.

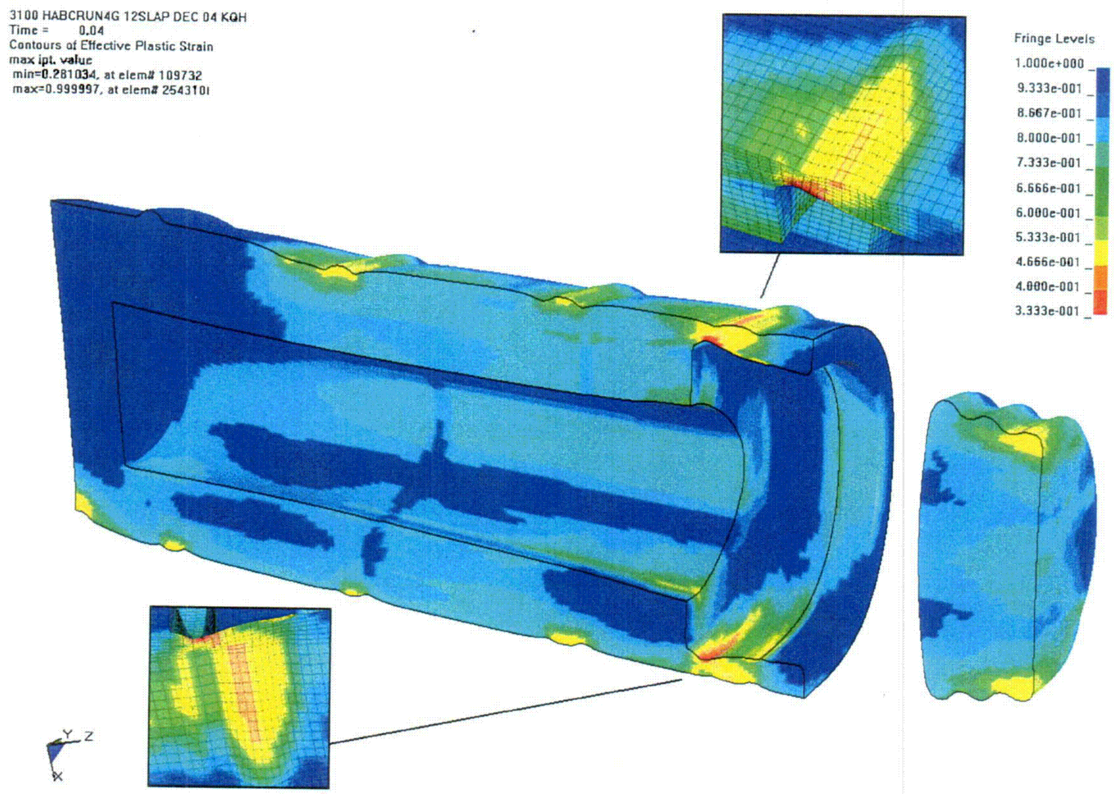

Fig. 1. Strain in the Kaolite - HABCrun4g.

C09

2-14 Justify the lack of pre-torqueing of the stud nuts or the CV nut ring in the finite element analysis.

Bolt /stud preload can have a significant effect on the resistance to shear loading. No explanation is given that takes the interaction of shear and tension into account.

Applicant Response:

Pre-loading of a bolted joint is important when all the components remain elastic. Pre-loading of bolted joints has been employed in the past on shipping package models and generally found not to be beneficial in the shipping container impacts. Drum studs that become highly loaded during an impact reach the plastic range, which releases any elastic pre-load. The pre-load stress in the CV flange throat is on the order of 125 psi, which is a very low elastic stress and is difficult to apply in LS-DYNA.

There are basically two methods to apply the pre-load to bolted joints. The first involves the use of the thermal coefficient of expansion to contract the bolt shank and hence induce a pre-load on the connection. This would involve choosing a material model for the bolt that allows thermal effects to be modeled. The second method is to prescribe an initial stress for the bolt shank elements. In the explicit run, both the thermally-induced load or the initial stress are dynamic events which will result in a transient relaxation; therefore, elastic stress time histories in the bolted joint will vary to a degree, which makes it difficult to determine what value should be used. The degree of relaxation is dependent on the local flexibility of the bolt/bolted joint. Therefore, an iterative solution is required to achieve the approximate desired bolting pre-load for a given configuration.

There is an added complication with the above methodology and the explicit solver if the pre-load demand is a significant percent of the elastic range of the bolt. If the bolted joint assembly is relatively flexible, then it may be found in the initial stress/relaxation run iterations that an initial stress in excess of yield is required to achieve a desired, relaxed pre-load.

An implicit run could be made which would remove the transient response. However, the foam and concrete materials in the remainder of the package model cannot be run in the implicit mode.

No changes to the SAR are suggested in response to this comment.

2-15 The SAR states that, "the lower nodes on the studs are allowed to merge with the angle nodes" (page 2-173). Describe what is meant by merge.

There are a variety of ways to construct transitions of this type. It is unclear what has been used.

Applicant Response:

In the preprocessor (TrueGrid), nodes that are in close proximity to one another are merged into a single node. A single node is formed from multiple nodes in the merging process. A user defined tolerance in TrueGrid input file defines which nodes will be merged. A tolerance value of 0.005 in. is used on the ES-3100 files. The command is found in the TrueGrid input files, near the end of the input files and takes the form of, "tp .005". Therefore, any nodes within the 0.005 in. tolerance are merged and become a single node.

The element mesh patterns at the base of the studs and the top surface of the angle are identical. Hence the nodes on the bottom of the stud and the top surface of the angle are coincident and within the tolerance of 0.005 in. These coincident nodes become a single node after the merging process.

In the TrueGrid input file, the command "merge" is stated typically just before the "tp .005" command. The "merge" command is not directly associated with the merging of the nodes, but is issued to move TrueGrid from the control phase to the merge phase. The command "tp .005" actually merges the nodes within the specified tolerance while in the merge phase.

No changes to the SAR are suggested in response to this comment.

2-16 Justify the termination of the transition near the midpoint of the diameter of the adjacent washer rather than at the exterior edge of the washer.

Figure 2.1.7 on page 2-173 of the SAR shows a shell to solid element transition for the drum lid. The load path in this region is from the nut to washer in bearing and from the washer to lid in bearing. Eliminating the bearing surfaces prematurely may have an impact on the stress distribution in this region.

Applicant Response:

The use of only shell elements to model the lid has been tried in the past. It was found that the contact between the lid and the stud was violated (breaks down) due to the lid nodes passing through the surfaces of the brick elements of the stud when subjected to high shear loadings. The decision was made to not attempt to alleviate this by varying the penalty value of the contact since this would change the contact of other components. The edge on contact of the shell elements with the stud would also be rounded due to the radius of contact and approaches a singular contact point with the stud.

If the lid were modeled with brick elements, then three elements through the thickness would be desired as a minimum. Three elements through the thickness would mean the width of the elements would be on the order of 0.06 in./3 = 0.02 in., making them the smallest of the stainless elements. The default solution timestep is used in the ES-3100 runs. LS-DYNA chooses a timestep considering the stress wavespeed through an element based on density and element dimensions. The use of three brick elements through the thickness would cause the solution timestep to decrease, thereby increasing the clock time for each of the runs.

Figure 1 shows an enlarged cross-sectional view of the stud/angle/lid model used on the ES-3100. The centerline of the stud is to the left in the figure. The nut, stud, washer and angle are all modeled with solid elements and their outlines are shown in Fig. 1. The blue colored elements depict the solid elements used in the 3100 lid model and the lid shell elements are modeled at the centerline and are shown by the magenta colored straight line. The purpose of the solid elements at the studs in the lid model is to provide a solid element contact surface with the stud during shear.

There is no contact discontinuity in the modeled lid. In shear, the full thickness of the lid shell engages the stud. Contact of the solid elements is on the outer element surfaces. Through the use of the *AUTOMATIC_SINGLE_SURFACE contact, the shell thickness is taken into account in the lid shell contact surface beneath the washer. The contact of the shell elements is at the one-half thickness radius at each node. The contact sphere at each node has been drawn in Fig. 1

with circles at each shell node location in the model. Therefore, the washer has full contact to the lid and the lid has full contact with the angle, since the lid thickness is taken into account.

This modeling approach has been used on several past shipping container analyses, including the DPP-2 and ES-2100. These containers were reviewed with independent analysis confirmation (ABAQUS) and licensed by NNSA.

No changes to the SAR are suggested in response to this comment.

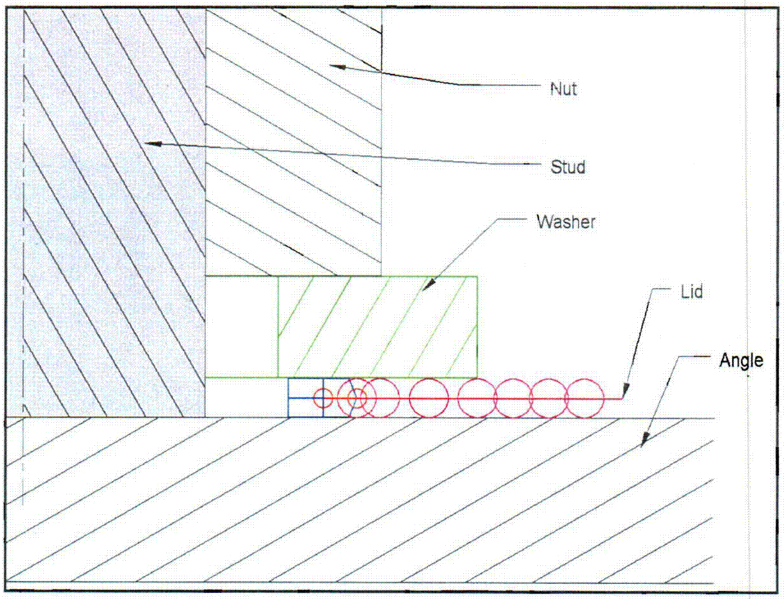

Fig. 1. Cross-sectional view of the lid assembly at a stud.

2-17 Justify the use of constrained Kaolite material properties in the analytical models rather than unconstrained Kaolite material properties.

Using constrained Kaolite material testing properties that were obtained to "simulate the deformation mode of accident conditions..." in effect is overestimating the material properties of the Kaolite. Using constrained Kaolite properties, and then constraining it again with the exterior drum in the ES3100 simulation in effect "double counts" the Kaolite contribution to strength.

Applicant Response:

Unconstrained material testing can be performed on classical cement type samples up to the point of classical engineering failure (initial cracking or spalling). However, unconstrained Kaolite material data cannot be obtained for the regions of strain which the package will see in one-dimensional test machines. The testing of unconstrained samples above the point at which initial cracks are formed results in spalling or degradation of the test specimen. The use of constrained Kaolite test data has been used on past NNSA-licensed shipping container analyses, including the DPP-2 and ES-2100.

C10

Y-12 had to develop a new method of testing our impact limiter material to generate the properties that better matched our material use (cast light weight concrete foam in a stainless steel shell). The foaming process occurred during the oven baking. The wet cast density was reduced from approximately 54 lb/ft^3 to a dry baked density of 24 lb/ft^3. The density loss of 30 lb/ft^3 was due to water loss. This process created a void volume of 48% for just the baked water removal, not accounting for the additional entrapped air during the casting process.

In 1995, calculations were performed that indicated that a 55-gal drum shipping package or crush plate would generate an impact at a speed around 527 in./s and stop in under 0.009 s generating G-loads of 188G's and straining the material to about 55% compression at the impact location (2.75 in. impact depth into a 5 in. insulation thickness). Of course, a stiffer impact limiter, smaller diameters, or stiffer steel design reduces the impact depth, which increases the G-load.

Most nonreinforced concrete tests are only concerned in the "quasi-static" elastic region up to and when the first brittle failure occurs which is under 0.5% strain. After the failure load, the material does not carry much of a load and can explode at high test velocities or pressures. Y-12 created a testing program that imitated the impact limiters using a sample cast in a 4" NPS schedule 40 steel pipe about 4 in. in length. As stated, the Y-12 impact limiter changes speed from 527 to 0 in./s in fewer than .009 s. Y-12 pushed its high speed impact tester to the limits to generate an average test velocity of around 180 in./s. Each sample was also tested to the high speed impact test limit of 10,000 lbf, generating a 790 psig compressive pressure. Depending upon the stiffness of the samples, high speed impact testing stopped at 42 to 52% strain. Again, this is over 100 times higher than the concrete brittle failure strains. Even at the 42% compressive strains, some small parts of the impact limiter model can get pinched causing a localized strain above the 42% measured maximums. In order to handle this strain-based anomaly for very small volumes strained above the tested limits, the curve was smoothly extrapolated to an assumed upper strain value. Modifications to the assumed upper strain value have little effect upon the final analysis results.

The following German conference paper discusses the use of the material type 26 (MAT_HONEYCOMB) to model an impact limiter of wood (spruce):

> Karl Klein, Hohannes Will and Thomas Seider, *Numerical Simulation of Wood Filled Impact Limiter with LS-DYNA*, 22nd CAD-FEM User's Meeting 2004, November 10-12, 2004, Dresden, Germany.

The material testing is described in the paper and an "encapsulated" test specimen was used. Good correlation between test data and analysis results is reported in the paper. For information, this paper is included (on the DVD) with this RAI response document.

No changes to the SAR are suggested in response to this comment.

2-18 **Demonstrate that the relative volume at full compaction and the density reported for the low stiffness ($V = 0.10$, $\rho = 27$ lb/ft^3), average stiffness ($V = 0.20$, $\rho = 22.4$ lb/ft^3), and high stiffness ($V = 0.12$, $\rho = 27$ lb/ft^3) are accurate.**

The numerical trends for the relative volume at full compaction as well as the density appear to be counterintuitive. The expectation would be that for relative volume at compaction, the average stiffness case would fall between the low stiffness case and the high stiffness case. This is particularly true given that the density of the average stiffness case is lower than both the low and high stiffness case.

Applicant Response:

This comment is related to RAI 2-13. The lock-up points for the Kaolite material are assumed points and cannot be supported by existing material test data. The data is required input for the *MAT_HONEYCOMB model. As explained in the RAI 2-12 and 2-13 responses, this is somewhat of an academic data point, since for the package impacts in question, the material does not reach this region of the material curve.

It is agreed that the assumed points are not logical, with the average stiffness relative volume of 0.2 falling outside the upper and lower stiffness bounding cases. The models were derived at different times and since it was known that this is an academic part of the curve (not reached in the impacts of concern), there was no effort to coordinate the lock-up point in the material models.

No changes to the SAR are suggested in response to this comment.

2-19 **Demonstrate that using engineering stress strain information for 304 stainless steel stud connectors is appropriate for use as input into LS-DYNA numerical models. True stress strain data is presented in the data tables in the SAR but was not used.**

LS-DYNA computes true stresses and true strains. The input for material should be true stress / true strain as well. Elongation at failure is not a failure strain but a measure of ductility that can under predict the true failure strain because it is dependent on gauge length. To obtain a true failure strain, one must utilize the reduction of area to calculate the localized strain at the location of necking. Additionally, the use of an engineering stress strain curve severely under predicts the amount of strain energy that can be absorbed by a material. The mixed use of failure strain and ultimate stress is also inappropriate for this analysis. Ultimate stress is generally not considered the point in which the material fails.

Applicant Response:

The use of the engineering stress/strain data in the model of the studs is conservative from a design point of view. There are many unknowns in the welded stud/lid joint such as static/dynamic friction, properties of the heat-affected zone of the weld and final geometry of the welded stud at the lid interface. There are also length tolerance differences that can be critical in situations such as the lid corner impact. In the corner impact, localized bearing of the stud onto the impacted object (steel plate at test site) can cause the stud to "dig in" and not slide relative to the impacted surface. This results in different loading demands placed on the bolt than are seen in

the analysis with the regulation required "rigid surface". Analyzing each of these perturbations would be extremely time consuming.

To demonstrate that this approach is conservative, the 30-ft impact of HABC-run2e was re-run with the material model of the bolt shank (material #16 in the model) changed from the engineering stress/strain data used in the elastic-plastic model to the power law model which is the true stress/strain relationship. The HABC-run2e is the lid corner impact.

In an effort to differentiate the two models, the model presented in the SAR with the engineering stress/strain model will be termed the "SAR" run. The 30-ft impact for the SAR HABC-run2e was documented in Section 7.3, pages 2-399 through 2-403 of the SAR, with the component maximum strain data recorded in Table 8.0.1 on page 2-457. The run files for the SAR HABC-run2e were included with the DVDs submitted with the SAR. The re-run of the SAR HABC-run2e with the power law model will be termed the "RAI" run, or RAI HABC-run2e. The run files for the RAI HABC-run2e are included on the DVD supplied with this RAI response document.

The LS-DYNA input file for the SAR was edited as follows:

1) a new title was used, and
2) the power law was used.

This can be verified by running the utility "CSDiff" on the two input files. Diff displays the differences between two files. The following is the resulting output from diff.

```
File difference report generated by CSDiff by ComponentSoftware on
7/25/2005 6:37 AM

Base file: D:\kqh\3100\3100_for_NRC\HABC Runs\run2e DVD 1 of
2\Dyna Input Files\di-2e.txt
Compared file:
D:\kqh\3100\3100_for_NRC\RAI-no1-questions\run2e\di-2e.txt

5c5
< 3100 HABC-run2e Corner Dec04 kqh
---
> 3100 HABC-run2e-rai1 Cr 7-05 kqh
239,243c239,243
< $ *MAT_POWER_LAW_PLASTICITY
< $ 16, 7.5130E-4, 2.81E+7, 0.29, 162738., 0.27208
< *MAT_PLASTIC_KINEMATIC
< 16, 7.3451e-4, 29e+6, 0.29, 34000., 93180.,
< ,,0.57
---
> *MAT_POWER_LAW_PLASTICITY
> 16, 7.3451E-4, 2.81E+7, 0.29, 162738., 0.27208
> $   *MAT_PLASTIC_KINEMATIC
> $   16, 7.3451e-4, 29e+6, 0.29, 34000., 93180.,
> $   ,,0.57
```

<------------------- End of report ------------------->

The "<" symbol shows the entries in the SAR input file and the ">" shows the entries for the RAI input file. The first difference noted was on line 5 of each file with the respective titles shown in the above listing. The second difference noted was in line #239 to 243 in each file. It can be seen that the engineering stress/strain relationship is used in the SAR run and that the power law material model is used in the RAI run. The "$" in the input files denote comment lines. Therefore, the engineering stress/strain model was active in the SAR model and the power law model is active in the RAI model. These are the only differences between the two input files. The results will be presented with the SAR HABC-run2e results presented first and the subsequent RAI HABC-run2e presented second on the same page to facilitate the comparisons.

The configurations at the end of the 30-ft impact (time = 0.015 s) in the vicinity of the impacting stud are shown in Figs. 1 (SAR) and 2 (RAI). Figure 1 is the same as the insert in the SAR Fig. 7.3.1 on page 2-402. Comparison of the figures shows that the shear deformation in the stud is more dramatic in the SAR model. This is to be expected with the relatively softer engineering stress/strain model compared to the true stress/strain values in the power law model.

The effective plastic strain in the studs is shown in Figs. 3 (SAR) and 4 (RAI). An enlarged view of the stud at the initial impact corner is included in each figure. Figure 3 is the same as the SAR Fig. 7.3.4 on page 2-403. The SAR model maximum strain is 0.523 in./in. and the maximum strain in the RAI model is 0.160 in./in. This result is to be expected due to the differences between the two material models.

The effective plastic strain in the lid is shown in Figs. 5 (SAR) and 6 (RAI). Figure 5 was not included in the SAR, but its maximum was recorded in the SAR Table 8.0.1, page 2-457 (0.2791 in./in.). The maximum strain in Fig. 6 (RAI) is 0.256 in./in. In each figure, the maximum is located near the stud on the plain of symmetry, opposite the initial impact.

In summary, the SAR models were run with an engineering stress/strain material model for the drum studs. The HABC-run2e was re-run with the true stress/strain power law model used for the drum studs. Comparing the two results shows that the deflection and strain in the engineering stress/strain models is greater than that of the true stress/strain model for the studs. The deflection pattern and strain fringes in the lid are about the same between the two models, with the plastic strain maximum being about 9% more when the engineering stress/strain model is used for the studs. The use of the engineering stress/strain model is considered conservative for the modeling of the simple stud configuration. If the engineering stress/strain material model were used on components whose deflections greatly affected other components, then its usage may not be conservative or a good model of real behavior. However, the use of a engineering stress/strain model for the bolting has been found beneficial from a design viewpoint and has been used on previous NNSA-licensed containers (i.e., DT-22 and DT-23).

No changes to the SAR are suggested in response to this comment.

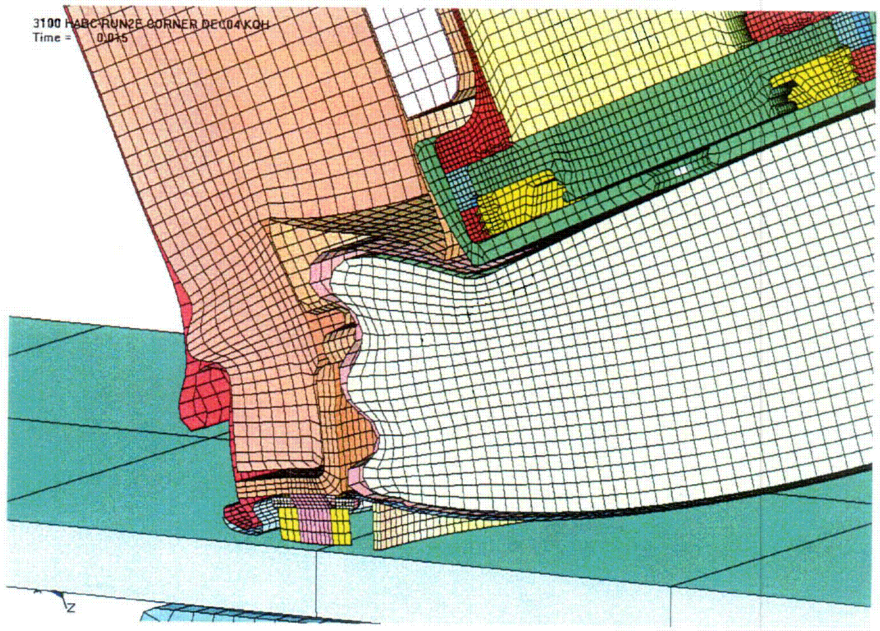

Fig. 1. SAR HABC-run2e, deformed configuration.

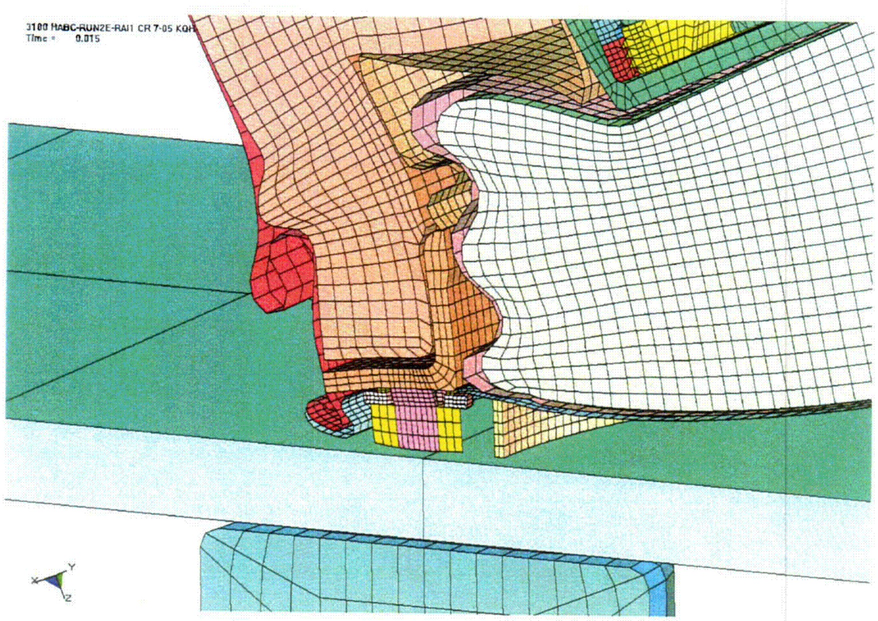

Fig. 2. RAI HABC-run2e, deformed configuration.

C11

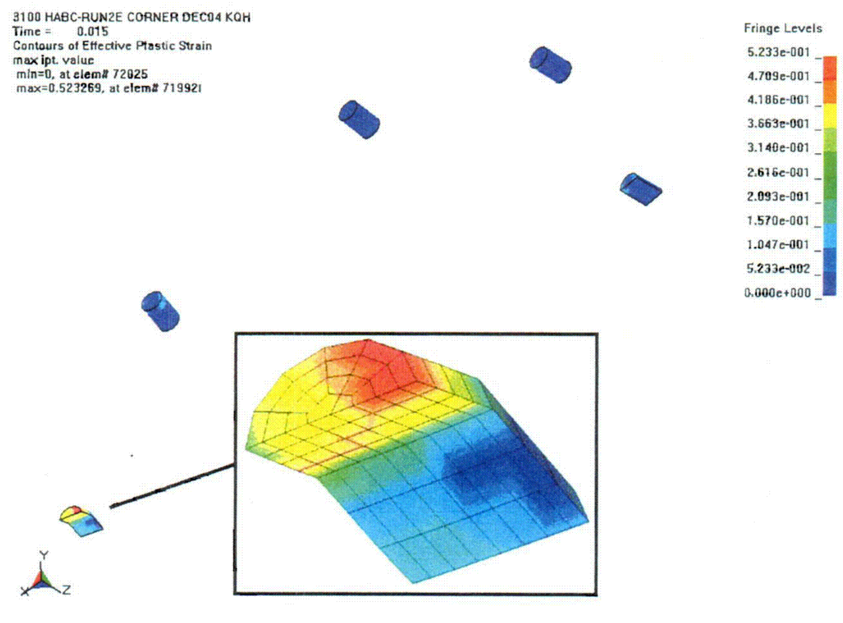

Fig. 3. SAR HABC-run2e, plastic strain in the studs.

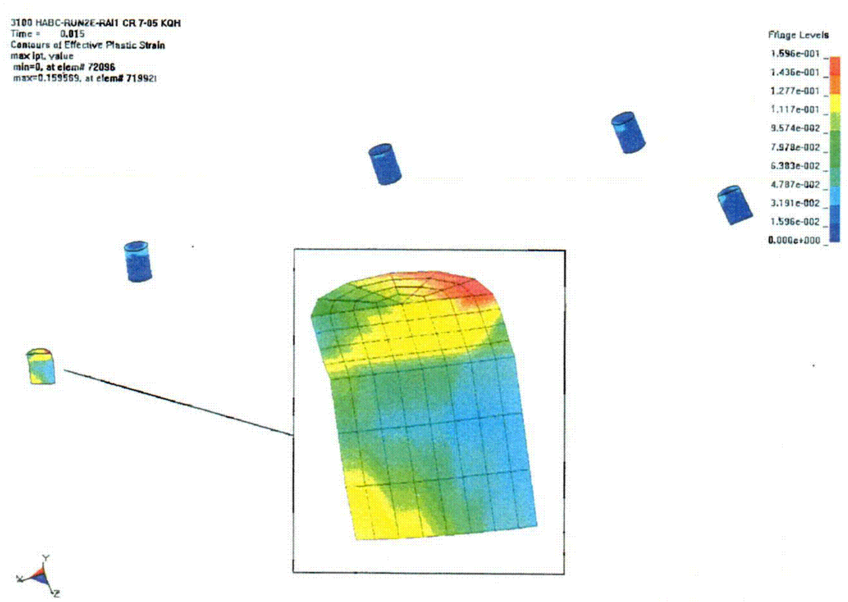

Fig. 4. RAI HABC-run2e, plastic strain in the studs.

C12

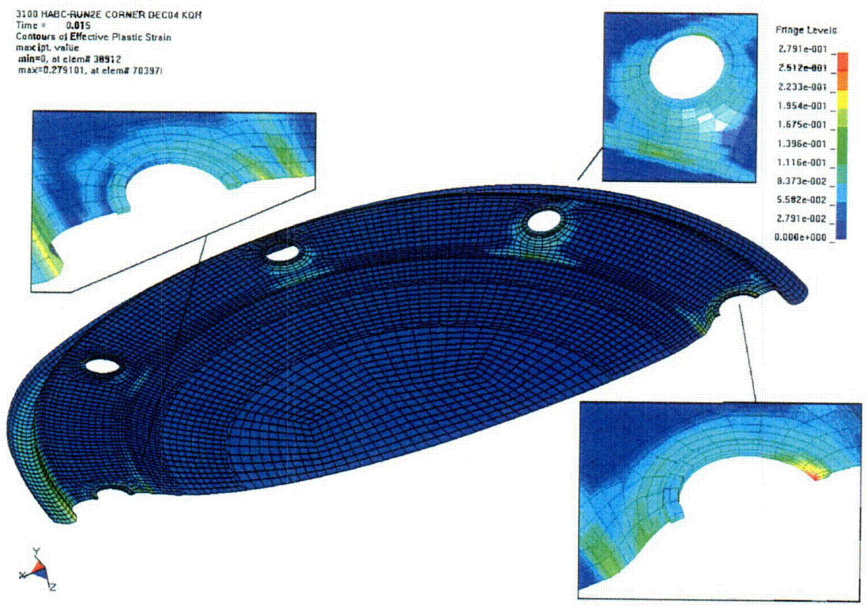

Fig. 5. SAR HABC-run2e, plastic strain in the lid.

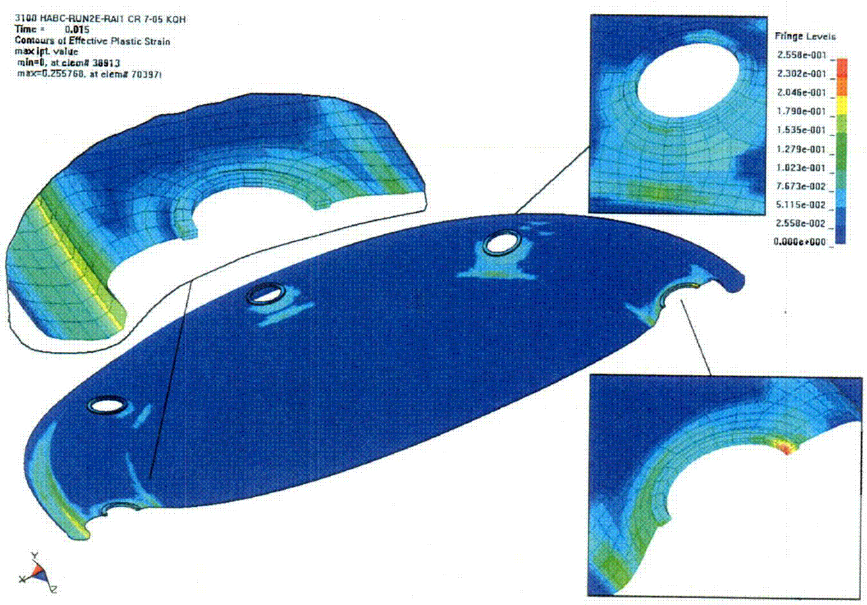

Fig. 6. RAI HABC-run2e, plastic strain in the lid.

C13

3.0 Thermal

3-1 Justify the assertion (on page 3-29 of the application) that "little or no hydrogen gas is generated inside the containment vessel due to thermal- or radiation-induced decomposition of the water vapor (limiting moisture content in oxide: 3 wt %) or polyethylene bagging (limiting plastic content: 500 grams). Provide a detailed and bounding calculation indicating the time evolution of the hydrogen concentration as it approaches a conservative flammable limit (5% volume in air). Address the generation of helium from the radioactive decay (alpha sources) of the contents. Include the effect of these gases upon the maximum operating pressures (normal and accident conditions). Modify the SAR so that a time limit for keeping a sealed and uranium-filled containment vessel is specified.

Applicant Response:

While the ES-3100 is in use, a periodic leakage-rate test is required on a frequency of one year. Therefore, if any materials are sealed in the package for more than one year, that package will not be shipped without first undergoing an annual inspection, which includes inspections and a leakage-rate test. Typically, any build-up of hydrogen gas in the package will be limited to the degree of generation that can take place in one year (maximum), which will be minimal for enriched uranium contents. If more than one year elapses while material is sealed in the ES-3100 containment vessel, that vessel will be opened and vented as part of the required annual inspection before the package can be shipped.

The Maintenance Program, described in Section 8.2 of the SAR (page 8-8), specifies the requirement for annual leakage-rate tests. More emphasis will be given. The text of Section 8.2 will be modified to indicate that the package can not be shipped if the annual inspection is not up-to-date, and that inspection will involve opening the containment vessel for visual inspection of all components and sealing surfaces, prior to leak testing.

In the SAR, replace the last sentence of Sect. 8.2 with the following sentences:

"Periodic maintenance of the ES-3100 shall be performed on an annual basis, and shall include visual inspections and leak tests. No ES-3100 shall be used unless maintenance documentation reflects the package is current on periodic maintenance. The periodic and maintenance refurbishment requirements are given below."

In the SAR, add the following sentence at the beginning of Sect. 8.2.5.2:

"The containment vessel lid must be removed before performing maintenance or periodic visual inspections on the containment vessel."

<u>Other Minor Editorial Comments noted:</u>

The text "mode" should be "move" on page 2-107, second to last line.
The text "tansportation" should be "transportation" on page 2-125 and 2-131 (section title).
The text "bare" should be "bear" on page 2-171, last paragraph, first sentence.
The text "plain" should be "plane" on page 2-173, second paragraph, second sentence.
The text "minium" should be "minimum" on page 2-458, third paragraph, fifth line.

Applicant Response:

The suggested changes have been made to the SAR.