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Safety Analysis Report, Y-12 National Security Complex, Model ES-3100 Package with Bulk HEU Contents

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BWXT Y-12, L.L.C.

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Y-12 NATIONAL SECURITY COMPLEX

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

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

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CONTENTS

CONTENTS continued

CONTENTS continued

CONTENTS continued

CONTENTS continued

CONTENTS continued

CONTENTS continued

LIST OF FIGURES

LIST OF FIGURES continued

LIST OF TABLES

LIST OF TABLES continued

LIST OF TABLES continued

ABBREVIATIONS AND ACRONYMS

ALARA	as low as reasonably achievable
AM	as-manufactured
ANC	Average Net Count
ANSI	American National Standards Institute
AS	allowable stress
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
Cat 277-4	Thermo Electron Corporation[1] Catalog No. 277-4™ (or Cat. No. 277-4)
CD	capacity discharge
CERCA	Compagnie pour l'Étude et la Realisation de Combustibles Atomiques
CFR	Code of Federal Regulations
CMTR	certified material test report
CoC	Certificate of Compliance
CSI	criticality safety index
CV	containment vessel
CVA	containment vessel arrangement
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPDM	ethylene-propylene-diene monomer
ETP	explicit triangular pack
FEA	finite element analysis
H/X ratio	hydrogen-to-fissile isotope ratio
HAC	Hypothetical Accident Conditions
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
k_{eff}	calculated neutron multiplication factor
LOD	loss on drying
LTL	lower tolerance limit
M.S.	margin of safety
MNOP	maximum normal operating pressure
MOCFR	moisture fraction inside the containment vessel
MOIFR	moisture fraction of the package external to the containment vessel
NCT	Normal Conditions of Transport
NLF	neutron leakage fraction
NRC	U.S. Nuclear Regulatory Commission
NTRC	National Transportation Research Center
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory
PGNAA	Prompt Gamma-ray Neutron Activation Analysis
ppb	parts per billion
ppm	parts per million
QA	quality assurance
QCPI	Quality Certification and Procurement
RCSB	Rackable Can Storage Box
SAR	safety analysis report

[1] Corporate name changed to Shieldwerx

SCALE	Standardized Computer Analysis for Licensing Evaluation
s_i	standard error
SRS	Savannah River Site
SS304	type 304 stainless steel
SST/SGT	Safe-Secure Trailer/Safeguards Transporter
TGA	thermogravimetric analysis
TI	transport index
TID	tamper-indicating device
TS	test sample
UNH	uranyl nitrate hexahydrate
UNX	uranyl nitrate crystals
USL	upper subcritical limit
VF	Volume Fraction
Y-12	Y-12 National Security Complex

REVISION LOG

Date	SAR Revision No.	Description	Affected Pages
38407	0	Original issue	All
08/15/05	0, 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
38753	0, Page Change 2	Page changes resulting from *Responses to Request for Additional Information #2*, Y/LF-761.	All Sections
38795	0, Page Change 3	Page changes resulting from *Responses to Request for Additional Information #3*, Y/LF-764.	1.38, 1.48, Appendix 1.4.1, 2-120, Table 6.4
38844	0, Page Change 4	Added polyethylene bottles and nickel alloy cans as convenience containers for authorized HEU contents. (CoC Revision 1)	Various pages in chapters 1, 2, 3 and 4.
08/21/06	0, Page Change 5	Revised equipment specifications for Kaolite and 277-4 neutron absorber. (CoC Revision 3)	Appendices 1.4.4 and 1.4.5.
11/15/06	1	Updated definition of pyrophoric uranium. Evaluated air transport. Revised criticality safety calculations to remove bias correct factors. Added a CSI option of 3.2. Increased mass of off-gassing material allowed in containment vessel. Increased carbon concentration in HEU contents. Increased Np-237 concentration is HEU contents. Added uranium zirconium hydride and uranium carbide as contents (TRIGA fuel). Revised equipment specifications for 277-4 neutron absorber. (CoC Revision 3)	All Sections

Date	SAR Revision No.	Description	Affected Pages
3/29/07	1, Page Change 1	Updated definition of TRIGA fuel for air transport and added TRIGA-related criticality safety cases.	title pages, viii, xi, xx, 1-12, 1-13, 1-20, 6-30, 6-54, 6-64, 6-66, 6-87, 6-119, 6-240 to 6-286, 6-385 to end
5/31/07	1, Page Change 2	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 4	title pages, xiii, xx, Section 1 and Section 6
6/30/07	1, Page Change 3	Revised SAR in response to RAIs dated May 9, 2007 in reference to CoC Revision 5	title pages, table of contents, Section 1, and Section 7
7/31/07	1, Page Change 4	Removed oxidation as an option for treating pyrphoric uranium metal	title pages, xx, 1-12, 1-201, 1-203, 1-212, 2-26, 7-4
8/28/07	1, Page Change 5	Modified TRIGA fuel definition to include fuel pellets with cladding	title page, xx, 1-13, 1-17, 2-4, 6-29, 6-30a, 6-66c, 6-66d, 6-73, 6-87, 6-119a
10/10/07	1, Page Change 6	-Revised criticality safety calculations to remove bias correction factors.	Table 6.2a and supporting calculations.
		-Added a CSI option of 3.2.	Table 6.2a and supporting calculations.
		-Increased mass of off-gassing material in containment vessel to allow Teflon bottles.	Figure 1.4, page 1-15, and Appendices 3.6.4 and 3.6.5.
		-Increased carbon and moisture concentration in HEU contents.	Pages 1-10 and 1-11, Table 6.2a and pages 6-31 and 6-52.
		-Increased Np-237 concentration is HEU contents.	Pages 5-1 to 5-4, and supporting calculations.
		-Revised equipment specifications for 277-4 neutron absorber.	Pages 1-83 and 1-97.
		-Details of alloys of uranium in contents definition.	Page 1-12.
		-More precise specification of maximum fissile mass in calculations (changed from 36 kg to 35.2 kg).	Administrative change affecting many pages. Removed round-off. No new calculations.

Note on revisions: Latest revision is shown as:

- Additions or changes are indicated by highlighted text
- Deletions are indicated by a mark in the margin

1. GENERAL INFORMATION

1.1 INTRODUCTION

This safety analysis report (SAR) presents the results of the safety analysis prepared in support of BWXT Y-12's request for licensing of the ES-3100 package with bulk highly enriched uranium (HEU) contents and issuance of a Type B Fissile Material Certificate of Compliance. This SAR, published in the format specified in the Nuclear Regulatory Commission (NRC) draft guidance DG-7003 and using information provided in NRC Regulatory Guide 7.10, demonstrates that the Y-12 National Security Complex (Y-12) ES-3100 package with bulk HEU contents meets the applicable requirements of 10 CFR 71 and 49 CFR Pts. 100–178.

To protect the health and safety of the public, shipments of radioactive materials are made in packaging that is designed, fabricated, assembled, tested, procured, used, maintained, and repaired in accordance with the provisions cited above. Safety requirements addressed by the regulations that must be met when transporting radioactive materials are containment of radioactive materials, radiation shielding, and assurance of nuclear subcriticality.

A general description and a summary of the evaluation of the packaging are presented in this section. Subsequent sections address structural (Sect. 2) and thermal (Sect. 3) responses to Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) and the packaging's ability to contain the radioactive materials when subjected to the requirements of 10 CFR 71.71 and 71.73, respectively. A shielding evaluation was prepared to ensure adequate nuclear radiation shielding (Sect. 5). Criticality evaluations that are unique to the contents were prepared to ensure nuclear subcriticality (Sect. 6). Sections 7 and 8 discuss the operating procedures, the new packaging acceptance tests, and the maintenance program for the planned use and refurbishment of the packaging.

The ES-3100 package was subjected to verification (analysis, similarity comparisons, tests, or a combination of these) for NCT and HAC. Full-scale packages were used for design verification testing (see Sects. 2 and 3). The ES-3100 package with bulk HEU content was verified solely on the ability of the package to meet the requirements of 10 CFR 71. Transport vehicle influence on the package is not required to meet 10 CFR 71 requirements.

The packaging verification activities (Sects. 2, 3, and 4), using content test masses of between 3.6 and 50.3 kg (8 and 111 lb), show that the packaging meets the containment requirements of 10 CFR 71. The shielding evaluations (Sect. 5) show that the packaging meets the NCT requirements of 10 CFR 71.47, *External Radiation Standards for all Packages*, and the HAC requirements of 10 CFR 71.51, *Additional Requirements for Type B Packages*. Based on the results of the thermal and shielding evaluations, the ES-3100 package with bulk HEU content may be shipped as a nonexclusive use package. The criticality evaluation (Sect. 6) shows that the packaging meets the requirements of 10 CFR 71.55, *General Requirements for Fissile Material Packages*, and 10 CFR 71.59, *Standards for Arrays of Fissile Material Packages*.

1.2 PACKAGE DESCRIPTION

A schematic of the ES-3100 shipping package is shown in Fig. 1.1, and an exploded view of the packaging components is presented in Fig. 1.2. The packaging design drawings (Appendix 1.4.8) provide material lists, dimensions, safety components, welding requirements, and gasket requirements. The proposed maximum gross shipping weight of the ES-3100 package with bulk HEU content is 190.9 kg (420 lb). The certification drawing of the ES-3100 can be found in Appendix 1.4.1.

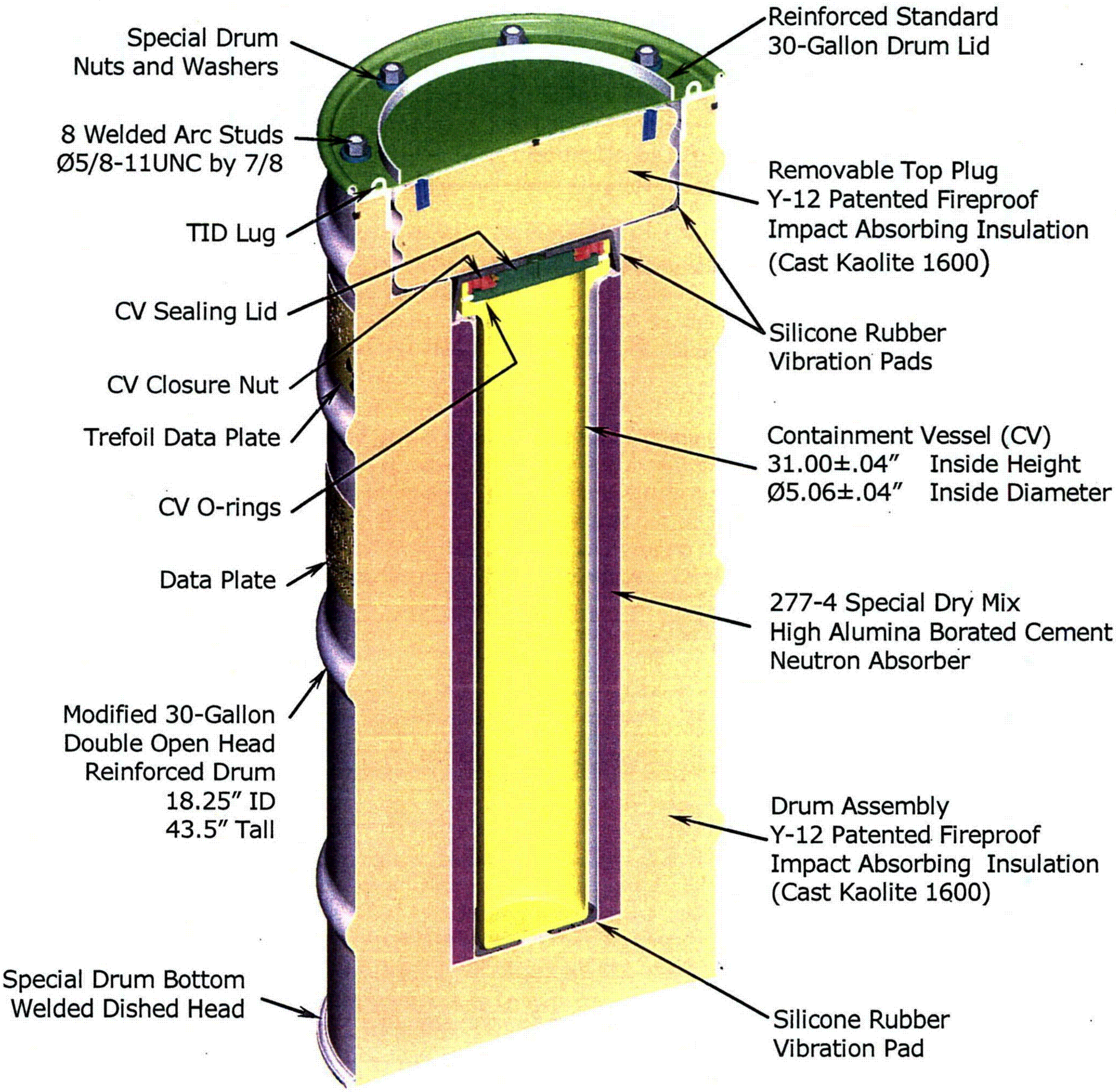


Fig. 1.1. Schematic of the ES-3100 shipping package.

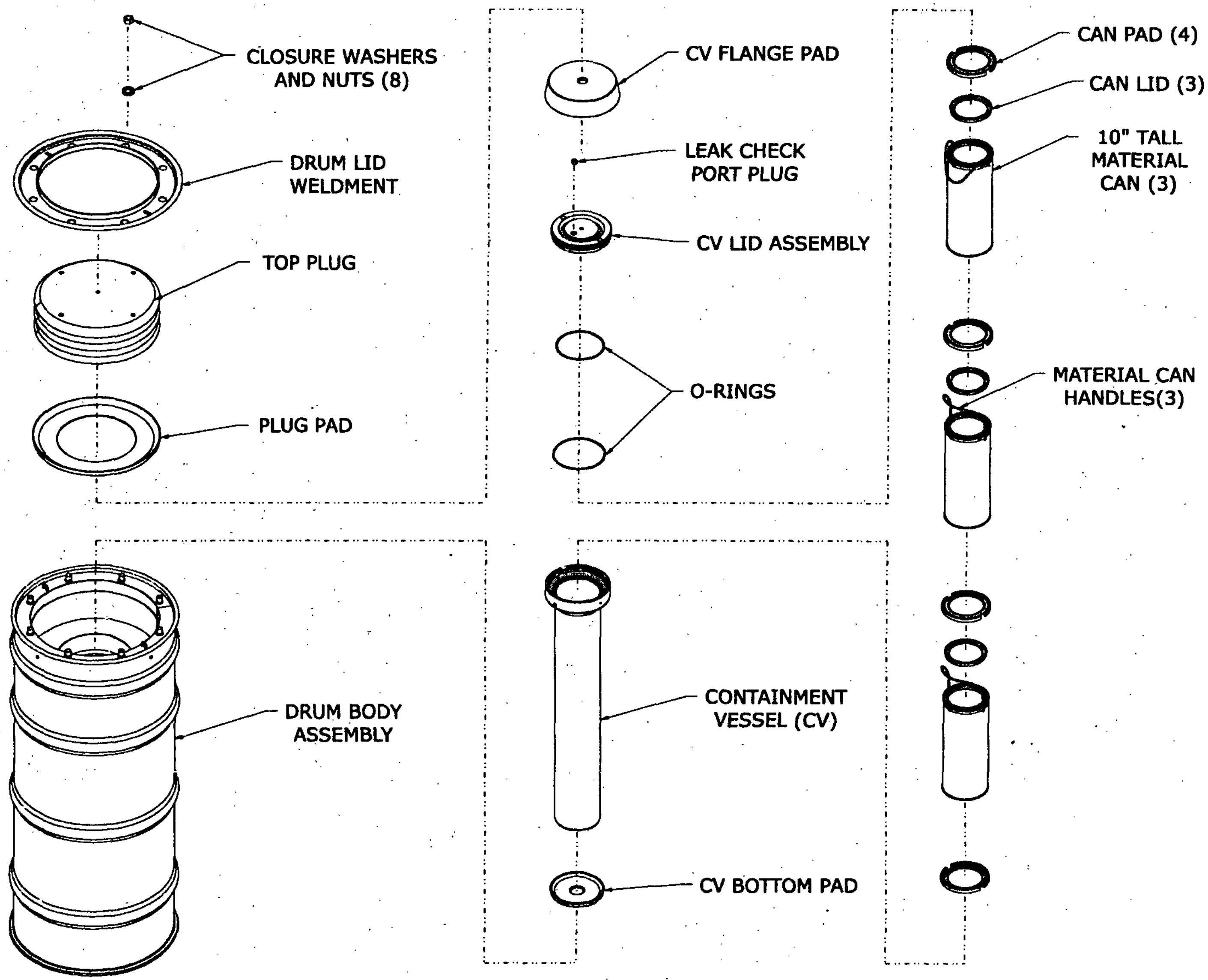


Fig. 1.2. Exploded view of the ES-3100 package with bulk HEU contents.

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 1.4.8]. 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 1.4.8). 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 1.4.8) is welded to the double open-head drum to create the bottom of the drum assembly. An inner liner (Drawing M2E801580A003, Appendix 1.4.8) 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 1.4.8). 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 1.4.8). 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 1.4.8). 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 1.4.8). This cavity is filled with a castable refractory (277-4 special dry mix) 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 1.4.8). 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 face of the internal flange. The body seams are welded. The following items are conducted in accordance with Sect. IX of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC, Sect. IX): welding procedures qualification and welders certification to these qualified procedures.

The drum has four circumferential hoops (chimes) formed into the body. The drum has four 0.795-cm (0.313-in.)-diam holes equally spaced around the circumference about 3.81 cm (1.50 in.) from the top rim to relieve pressure in the drum in the event of a thermal accident (Drawing M2E801580A002, Appendix 1.4.8). Plastic plugs (Nylon 6/6, Micro Plastic, Inc., Item Number 62MP0312) are placed into these holes from the outside to prevent leakage of water into the drum during NCT and storage. The drum is fabricated with a data plate, trefoil data plate, paint, and two lid TID lugs for use with tamper-indicating devices (TIDs). The two electrochemically etched data plates are affixed to the exterior of the drum body in the locations, and with the methods, indicated on Drawing M2E801580A031 (Appendix 1.4.8). The trefoil data plate (M2E8015803A010-1) provides the owner's return address, container model, container serial number, and the trefoil symbol. The other data plate (M2E801580A010-2) provides the required DOT markings—certificate number, maximum gross weight, and "Type B" designation.

The removable lid is attached to the drum body by a flange with eight silicon bronze, 5/8-11-UNC-2B hex-head nuts [C65100, American Society for Testing and Materials (ASTM) F-467] with stainless-steel washers. These nuts are tightened onto the weld studs (304 or 304L stainless steel, 5/8-11-UNC-2A, ASTM A-493 or F-593) to 40.67 ± 6.78 N·m (30 ± 5 ft-lb) of torque with no sequence specified.

The top plug is 36.5 cm (14.37 in.) in diameter and 13.41 cm (5.28 in.) in height at the center. The skin is made from 16 gauge [~0.152-cm (0.0598-in.)-thick] type 304 or 304L stainless steel and is filled with Kaolite 1600.

The drum assembly also contains three silicone rubber pads. The first pad (CV bottom pad) is placed on the bottom of the innermost liner to support the containment vessel bottom during transport. The second pad (CV flange pad) is placed on top of the containment vessel lid during transport. The third pad (plug pad) is placed on the top shelf of the mid-liner to cushion the top plug during transport. The locations of these three pads are shown on Drawing M2E801580A001 (Appendix 1.4.8), and the dimensions of the pads are shown on Drawing M2E801580A009 (Appendix 1.4.8).

The drum is designed so that lifting can be accomplished with a forklift. It can either be placed on the tines of the forklift from below, or a pincher assembly can be placed on the forklift and used to grasp the exterior of the drum assembly. Based on analytical results for a similar package (the BWXT Y-12 Model ES-2100), forklift gripping forces of up to 5400 lb can be used with no detrimental effects on the package.

No tie-down devices are integral to the package, nor can any features be used for these purposes. The ES-3100 package is designed to be shipped in accordance with the safe-secure trailer/safeguards transporter (SST/SGT) requirements.

1.2.1.2 Insulation

The void area formed by the drum and the attached inner liner is filled with an inorganic castable refractory material (Kaolite 1600) made by Thermal Ceramics, Inc., which acts as both a thermal insulating and an impact limiting material. The top plug assembly, which is placed between the containment vessel and the drum lid, is also filled with Kaolite 1600. This material is a mixture of cement and vermiculite and has a nominal cured density of ~358.8 kg/m^3 (22.4 lb/ft^3). Additional information regarding the characteristics and properties of this material is presented in Appendix 2.10.3. Casting takes place while the drum is being vibrated in an inverted orientation to ensure that the castable material penetrates into all areas in the void space formed by the drum and the inner liner and that no considerable voids are formed during this process. The Kaolite material is then baked in a furnace at elevated temperatures [~260°C (500°F)] as prescribed in Manufacturing Process Specification, JS-YMN3-801580-A003, *Manufacturing Process Specification for Casting Kaolite 1600 into the ES-3100 Shipping Package,* the specification which controls manufacture of Kaolite 1600 for the ES-3100 (Appendix 1.4.4). The use of a thermal ceramic material, such as Kaolite 1600, as an impact limiting/thermal insulating material in a Type B fissile material shipping package has been previously used in other Y-12 owned and licensed packages (i.e., ES-2100 and DPP-2). The original decision to use this material was the result of considerable research. This manufacturing process is protected under U.S. Patent 6,299,950 B1 (Byington et al. 2001). The United States Government has rights in this invention pursuant to Contract No. DE-AC05-84OR21400 between DOE and BWXT Y-12.

One of the design goals of Y-12's packaging development program was to build a shipping package entirely of materials that do not char, burn, or thermally decompose when exposed to the temperatures and conditions associated with HAC [800°C (1475°F)]. Cellulosic fiber board and polyurethane foams, typically used for packaging applications, undergo decomposition when exposed to these HAC thermal conditions. During thermal decomposition, these materials off-gas, producing conditions that are potentially detrimental to the performance of the package. The hot gases generated within the packaging can transfer heat to inner regions adjacent to the containment closure seals. Under severe circumstances, this process could lead to loss of containment due to overheating of containment seals. The Kaolite material is nonflammable and will not undergo chemical decomposition at temperatures below 1260°C (2300°F). When Kaolite is heated above 100°C (212°F), water vapor from free water contained within the casting will form. Pressurization of the drum and top plug is prevented by pressure relief holes (vent holes) located near the top of the drum and on the top center of the top plug (see Sect. 1.2.1.1 and Drawings M2E801580A002 and M2E801580A008, Appendix 1.4.8). The cured Kaolite 1600 material does not decompose, and thus there are no exothermic chemical reactions that could produce superheated off-gasses.

Extensive testing of Kaolite 1600 was performed by the Y-12 Development Division to determine the performance of the material for this type of application (Oakes, Appendix 2.10.3). Testing showed that Kaolite 1600 has a tremendous ability to absorb shock over a wide range of material densities, curing temperatures and times, and material temperatures. The 10 CFR 71.73 HAC testing documented in Sect. 2.7 demonstrates that Kaolite 1600 is a robust impact limiter and good thermal insulating material for Type B shipping containers. Post HAC drop testing radiographs of a similar package, the ES-2100, showed some minor cracking of the Kaolite structure in some cases. However, subsequent thermal testing of these ES-2100 packages demonstrated that these cracks were inconsequential to the package's ability to meet regulatory requirements.

Insulation thicknesses within the liner/drum volume adjacent to the side walls of the ES-3100 containment vessel are at least 4.27 cm (1.68 in.), with typical thicknesses of approximately 12.10 cm (4.77 in.). Below the containment vessel, the minimum thickness of insulation is 10.05 cm (3.96 in.), and the top plug, which is above the containment vessel, includes a 12.55-cm (4.94-in.) thickness of insulation.

1.2.1.3 Shielding

The ES-3100 packaging does not require dedicated shielding materials of specific design to control external radiation levels for the bulk HEU contents. However, the intervening packaging materials of construction (stainless steel of the drum and containment vessel, the Kaolite material, and the 277-4 material) provide some attenuation of the relatively low levels of penetrating radiation emitted by the contents. The amount of shielding modeled for the NCT analysis is represented by the thickness and density of the materials reported in Sects. 1.2.1.1, 1.2.1.2, and 1.2.2 and the packaging dimensions (Appendix 1.4.8). HAC physical testing showed that the containment vessel and insulation remain confined within the drum assembly. However, the HAC shielding evaluation conservatively assumes that only the containment vessel remains for shielding purposes (i.e., no shielding credit is taken for the drum and insulation in the HAC analysis).

1.2.1.4 Nuclear criticality safety

The packaging materials of construction in the ES-3100 provide neutron absorption (stainless steel and 277-4) and reflection (stainless steel and insulation). The 277-4 (or Cat 277-4 as it is sometimes referred) material is a noncombustible cast neutron-absorbing material. This material is cast into the innermost liner of the package adjacent to the containment vessel as shown in Fig. 1.1. The material is a high alumina borated concrete composed of aluminum, magnesium, calcium, boron, carbon, silicone, sulfur, sodium, iron, and water. The 277-4 material was manufactured specifically for the ES-3100 package by adding boron carbide to a standard material (Cat No. 277-0) and increasing the boron content from 1.56 wt % to 4.23 wt%. Additional information on the neutron-absorbing characteristics of this material is presented in Appendix 6.9.3. Properties of the 277-4 material are presented in Table 2.17 and Appendix 2.10.4. The cast material has a nominal density of 1681.9 kg/m^3 (105 lb/ft^3). The procedure for mixing this material and casting it into the ES-3100 shipping package is documented in JS-YMN3-801580-A005, *Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package* (Appendix 1.4.5).

Although shown by tests up to HAC as not being credible, the criticality analysis considers water leakage into the containment vessel in accordance with 10 CFR 71.55(b). Depending on the content being shipped and the shipping configuration being used, criticality safety index (CSI) values for the ES-3100 package may range from 0 to 3.2 (see Table 1.3).

1.2.2 Containment System

A single containment vessel is used in the ES-3100 shipping package for the transport of bulk HEU contents. The ES-3100 containment boundary (consisting of the containment vessel body, lid assembly, and inner O-ring) is shown in Fig. 1.3.

During fabrication, all ES-3100 containment vessels will be inspected and tested to the requirements specified on the design drawings (Appendix 1.4.8) and equipment specification (Appendix 1.4.3). Certification documents received from the vendor with each component acknowledge the use of these drawings and specifications. These certifications are on file with the Y-12 Quality Organization.

The containment boundary of the ES-3100 package is a pressure vessel that is designed, fabricated, examined, and tested in accordance with the *ASME Boiler and Pressure Vessel Code,* Sect. III, Division I, Subsection NB (B&PVC, Sect. III, Div. I). The ES-3100 containment vessel body is constructed of 304L stainless steel and may be fabricated by one of two methods. The first method uses a standard 5-in., schedule 40 stainless-steel pipe (ASME SA-312 Type TP304L), a machined flat-head bottom forging (ASME SA-182 Type F304L), and a machined top flange forging (ASME SA-182 Type F304L). Each of

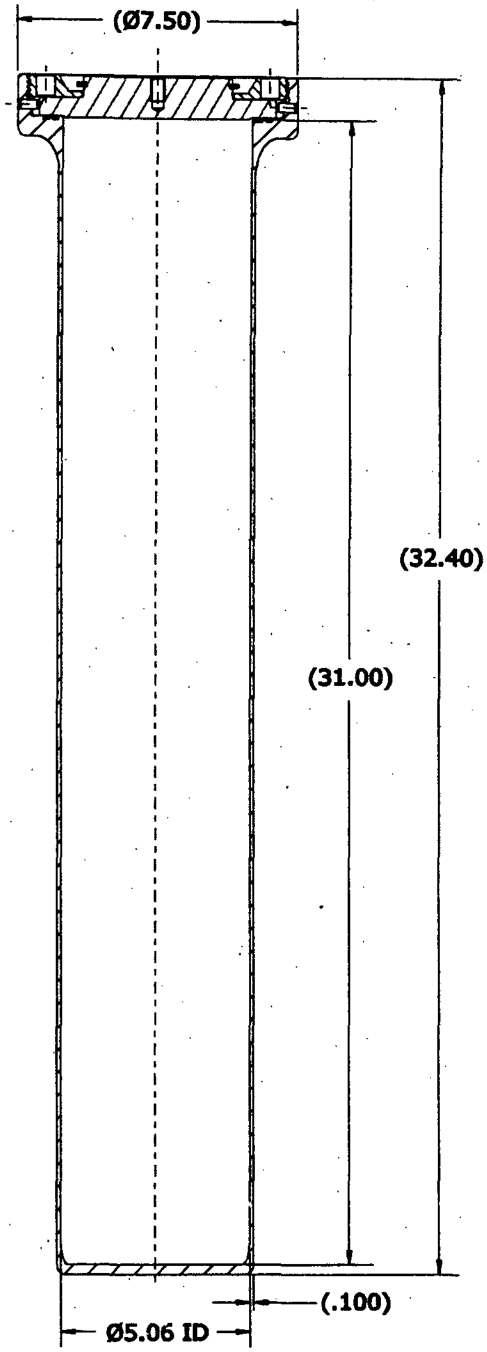


Fig. 1.3. Containment boundary of the ES-3100 shipping package.

these pieces is joined with circumferential welds as shown on Drawing M2E801580A012 (Appendix 1.4.8). The top flange is machined 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 fabrication method for the ES-3100 containment vessel 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 1.4.8). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.4.8) is machined from Type 304 stainless-steel bar with final material properties in accordance with ASME SA-479. The containment vessel closure nut 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 provide a leak-check port between the elastomeric O-rings, and notched along the perimeter to engage two dowel pins. The swivel hoist ring is only intended for use when loading and unloading the containment vessel. The swivel hoist ring will be removed for shipment. The lid assembly, with the O-rings in place on the containment vessel 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.

The use of a design that includes two O-ring seals permits assembly verification leak testing of the containment vessel by measuring the leak rate from the volume between the inner and outer O-rings. 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. All O-rings on this containment vessel are fabricated to ASTM D2000, M3BA712A14B13F17.

The inner diameter of the containment vessel is 12.852 cm (5.06 in.) and the usable height inside the containment vessel is 78.74 cm (31.0 in.). The wall thickness of the body excluding the flange is 0.254 cm (0.10 in.). The maximum nominal diameter of the containment vessel body is 19.05 cm (7.50 in.). The nominal thicknesses of the containment vessel's flat bottom is 0.635 cm (0.25 in.). The overall height of the containment vessel without the swivel hoist ring is 82.296 cm (32.40 in.). The containment vessel drawing number, drawing revision, and serial number are electroetched onto the side of the containment vessel body, as well as onto the top of the sealing lid and the closure nut (Drawing M2E801580A011, Appendix 1.4.8). All outer surfaces, unless otherwise specified, are either sand- or bead-blasted, buffed, or sanded to a matte finish. No penetrations, connections, or fittings into this sealed container exist.

1.2.3 Contents

The ES-3100 shipping package will be used to ship bulk HEU in the form of oxide (UO_2, UO_3, or U_3O_8), uranium metal and alloy in the form of solid geometric shapes or broken pieces, uranyl nitrate crystals (UNX) and fuel elements from Training, Research, Isotopes, and General Atomics (TRIGA) reactors. The ES-3100 package has been designed to accommodate a maximum of 24 kg of oxide or UNH crystals and a maximum of 35.2 kg of metal and alloy. The maximum weight of all contents (including convenience cans or bottles, can spacers, polyethylene bagging and other packing materials) shall not exceed 40.82 kg (90 lb). The maximum concentration of uranium isotopes permitted in the ES-3100 content are listed in Table 1.1. In addition to the uranium isotopes shown in Table 1.1, transuranic isotopes (with the

Table 1.1. Uranium concentration limits

Uranium isotope	Limit
^{232}U	0.040 μg/gU
^{233}U	0.006 g/gU
^{234}U	0.02 g/gU
^{235}U	1.00 g/gU
^{236}U	0.40 g/gU
^{238}U	1.00 g/gU

exception of ^{237}Np) may be present in the contents at a maximum concentration of 40.0 μg/gU. The concentration of ^{237}Np is limited to 0.0250 g/gU. Unless otherwise specified, the contents described in this section pertain to ground transport only. A discussion of contents of air-transport is included at the end of this section.

HEU Oxide

The HEU oxide content in the ES-3100 package includes UO_2, UO_3, and U_3O_8. Seven different oxide categories have been identified (Appendix 1.4.7). Maximum overall uranium isotopic weight percents representative of all seven oxide categories are presented in Table 1.2. The physical form of all contents is dense, loose powder which may contain clumps. Moisture content in oxide is limited to 6 wt % water (Note: loading restriction #7 in Sect. 1.2.3.8 also applies). Theoretical densities of UO_2, U_3O_8 and UO_3 are 10.96 g/cm^3, 8.30 g/cm^3, and 7.29 g/cm^3, respectively. Actual working densities are expected to be significantly less. Oxide may be shipped in tin-plated carbon steel, stainless steel, or nickel-alloy convenience cans, or Teflon or polyethylene convenience bottles.

Table 1.2. Bounding uranium isotopic concentrations in oxide

Isotope	Bounding limit
^{232}U	40 ppb
^{233}U	200 ppm
^{234}U	2.0 wt %
^{235}U	97.7 wt %[a]
^{236}U	40.0 wt %
^{238}U	80.0 wt %

[a] ^{235}U must be ≥20 wt %

For convenience, the seven oxide categories are referred to as Groups 1-7. Groups 1 to 6 are product oxides and Group 7 is skull oxide. These groups are briefly described below.

Group 1 oxides are in the form of UO_x. Material from this group contains at least 83.0% uranium by weight and displays typical isotopic content (≤0.977 g^{235}U/gU, ≤0.014 g ^{234}U/gU, ≤0.010 g^{236}U/gU,

≤0.040 μg ^{232}U/gU, ≤50.0 μg ^{233}U/gU with the balance of the uranium being ^{238}U).

Group 2 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and displays typical isotopic content (≤0.977 g ^{235}U/g U, ≤0.014 g ^{234}U/g U, ≤0.010 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 3 oxides are contaminated with up to 40 μg Pu/g U and are in the form of UO_x. Material from this group contains at least 83.0% uranium by weight and displays typical isotopic content for uranium (≤0.977 g ^{235}U/g U, ≤0.014 g ^{234}U/g U, ≤0.010 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 4 oxides are in the form of U_3O_8. Material from this group contains at least 83.0% uranium by weight and displays typical isotopic content (≤0.977 g ^{235}U/g U, ≤0.014 g ^{234}U/g U, ≤0.010 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 5 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and displays typical isotopic content (≤0.977 g ^{235}U/g U, ≤0.014 g ^{234}U/g U, ≤0.010 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U). This material may contain considerable activity in the form of unspecified beta emitters.

Group 6 oxides are in the form of UO_x. Material from this group contains at least 20.0% uranium by weight and may display unusually high isotopic concentrations of ^{233}U, ^{234}U, and ^{236}U (≤0.977 g ^{235}U/g U, ≤0.020 g ^{234}U/g U, ≤0.40 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤200.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U).

Group 7 oxides are in the form of U_3O_8. Material from this group is a mixture of graphite and U_3O_8, also referred to as skull oxides. The uranium concentration is up to 84.5% by weight and enrichment is up to 93.2% by weight. Concentrations of other uranium isotopes are ≤0.014 g ^{234}U/g U, ≤0.010 g ^{236}U/g U, ≤0.040 μg ^{232}U/g U, ≤50.0 μg ^{233}U/g U with the balance of the uranium being ^{238}U. The carbon content in these oxides, is limited to 921 g per ES-3100 package.

The oxides in Groups 1, 3, 4 and 7 are high purity uranium oxide purity (the remainder is only trace impurities). Oxide Groups 2, 5, and 6 are listed to contain at least 20% uranium by weight, which allows up to 80% non-uranium material. As oxides, depending on the purity and chemical form, 3% to 17% of the total material composition will be oxygen, leaving up to 77% impurity or "filler". These three oxide groups include a range of scrap and recovered materials. For the least pure uranium oxides, the majority of the filler material is aluminum oxide (from recovered alumina traps or from oxidized uranium-aluminum alloys). Other materials that occur in appreciable quantities in some scrap materials are oxides and compounds of boron, calcium, iron, sodium, lead, zinc, magnesium, copper, molybdenum, and tungsten. These materials are essentially inert from the standpoint of criticality safety and chemical interaction with the ES-3100 convenience cans and bottles identified in this section for the shipment of oxides.

HEU Metal and Alloy

HEU metal and alloy (alloys of uranium with aluminum or molybdenum) may be in the form of solid geometric shapes. Solid shapes may include the following:

1. spheres are not included as a content shape;
2. cylinders having a diameter no larger than 4.25 in. (maximum of one cylinder per convenience can);

3. square bars having a cross section no larger than 2.29 in. × 2.29 in. (maximum of one bar per convenience can); and

4. slugs having dimensions of 1.5 in. diameter × 2 in. tall (maximum of 10 per convenience can).

With the exception of slug content, solid HEU metal and alloy content of specified geometric shapes shall be limited to one item per convenience container. HEU bulk metal and alloy contents not covered by the geometric shapes category specified above will be in the broken metal category, and will be so limited.

Alloys of uranium may include aluminum or molybdenum. Uranium-aluminum alloys are up to 75% aluminum. Uranium-molybdenum alloys are typically 1 to 12% molybdenum. Uranium/molybdenum alloys may be plated with, clad with, or contain traces of aluminum, gold, stainless steel, nickel and/or chromium.

HEU bulk metal and alloy contents in the broken metal category may be of unspecified geometric form. HEU bulk metal and alloy in this category may also be of a specific shape where one or more of the characteristic dimensions vary from piece to piece (i.e., the height, width, length, radius, etc.).

For pyrophoric considerations, HEU metal and alloy must meet the following restrictions:

1. Uranium metal and alloy (broken) pieces must have a surface-area-to-mass ratio of not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve.

2. Particles and small shapes which do not pass the size restriction tests in #1, and powders, foils, turnings, and wires, are not permitted unless they are in a sealed, inerted container.

Metal and alloy may be shipped in tinned-carbon steel, stainless steel, or nickel-alloy convenience cans.

Uranyl Nitrate Crystals

Uranyl nitrate crystals (UNX) are formed by dissolving uranium metal or any of the uranium oxides in nitric acid. Uranyl nitrate hexahydrate (UNH) has a chemical formula of $UO_2(NO_3)_2 + 6\ H_2O$. This most reactive form is used as the bounding composition for uranyl nitrate crystals in the criticality evaluation. Therefore, for UNX contents, X must be less than or equal to 6. The theoretical density of UNH crystals is 2.79 g/cm^3; however, the working densities will be less.

The user of the ES-3100 for UNX shipments will be required to use non-metallic containers only (such as Teflon or polyethylene bottles) as the convenience container.

TRIGA Fuel Elements

Fuel pellets from Training, Research, Isotopes, and General Atomics (TRIGA) reactor elements are authorized to be shipped in the ES-3100. The fuel shall be unirradiated. The TRIGA fuel shall be in the form of uranium zirconium hydride (UZrHx), where x ≤ 2. Fuel from three types of TRIGA fuel elements are allowed; TRIGA Standard Fuel Elements (SFE), Instrumented TRIGA Standard Fuel Elements (FTC), and TRIGA Fuel Follower Control Rods (FFCR). These fuel elements have three fuel pellets (or sections) per element. The fuel pellets from the SFE's and FTC's to be shipped are 8.5 wt% uranium and 70% enriched. Fissile loading is 45.33 g ^{235}U per pellet (136 g ^{235}U per element) and the dimensions are 5 inches in length and 1.44 inches in diameter. The fuel pellets from the FFCR's to be shipped are 8.5 wt% uranium and 70% enriched. Fissile loading is 37.33 g ^{235}U per pellet (112 g ^{235}U per element) and the dimensions are 5 inches in length and 1.31 inches in diameter. Specific TRIGA fuel element data is given in Table 1.4.

TRIGA fuel may be shipped as crimped fuel elements or as UZrHx fuel pellets (if disassembled), both of which shall be packed into convenience cans prior to shipment. Convenience cans of 4.25-inch diameter by various lengths shall be used. Fuel pellets loaded into convenience cans shall be up to 5 inches in length (full-length) and no more than three full-length pellets shall be loaded into a convenience can. Crimped fuel rods are clad fuel pellets and can be up to 15 inches in length (full-length of the fuel section from one fuel element). Cladding material is stainless steel or aluminum. Only the fuel section of the TRIGA fuel element is allowed to be shipped (Fig. 1.5); however, there may be residual cladding up to ½ inch in length at either end of the crimped fuel rod. Up to three 15-inch long crimped fuel elements shall be loaded into a single 17.5-inch long convenience can for shipping (Fig 1.4). Maximum loading of bare fuel pellets and crimped fuel elements shall be 3 fuel element equivalence per ES-3100 containment vessel. Only 70% enriched TRIGA fuel will be shipped. For SFEs and FTCs, the maximum allowable loading is 408 g ^{235}U per package, and for FFCRs, the maximum allowable loading is 336 g ^{235}U per package. No spacer cans are required.

<u>**Air Transport**</u>

Contents for air transport of the ES-3100 shall include HEU in the form of unirradiated TRIGA fuel pellets or crimped fuel elements. The characteristics of the air transport contents shall be similar to the ground transport contents, but the fissile loading per package will be as follows:

> TRIGA fuel elements and pellets - 3 fuel element equivalence per package. Fuel shall be 70% enriched and in the form of SFEs, FTCs, and FFCRs. Maximum fissile loading for SFEs and FTCs shall be 408 g ^{235}U per package, and for FFCRs, the maximum allowable load shall be 336 g ^{235}U per package.

1.2.3.1 Radioactive/fissile constituents

Fissile material mass loading limits for the contents of the ES-3100, as determined by criticality analyses, are presented in Table 1.3 (for ground transport only). For the ES-3100 package with bulk HEU content, the maximum number of A_2s is 294.00 (at 70 years) and the maximum activity is 0.3243 Tbq (at 10 years) [Table 4.4].

1.2.3.2 Chemical and physical form

The fissile material contents are in solid (HEU metal, alloy, or TRIGA fuel), crystalline (UNX) or powder (HEU oxide) form. Some moisture (up to 6 wt.%) may be present in the HEU oxide material, thereby making the oxide content clump together.

1.2.3.3 Reflectors, absorbers, and moderators

The reflectors, absorbers, and moderators present in the ES-3100 package are those associated with the materials of construction. For example, the thermal insulation acts as a neutron reflector to the contents of a single package and as a neutron moderator in an array of packages. The degree of neutron moderation is a function of the hydrogen content in the Kaolite 1600 and 277-4 materials. The stainless-steel materials of the containment vessel and the drum also act as neutron reflectors to the contents of a single package but act as neutron absorbers in an array of packages. The nuclear properties of the materials of construction and of the contents are important and have been taken into account in the criticality safety evaluation (Sect. 6). In addition to the materials of construction in the ES-3100 shipping package mentioned above, the 277-4 material has been specifically added to the ES-3100 package for the purpose of enhancing the neutron absorption characteristics for safety purposes (see Sect. 6 for additional discussion of the neutron-absorbing characteristics of this material).

Table 1.3. Authorized content [a] and fissile mass loading limits [b,c] for ground transport

Content description		Enrichment	CSI	No spacers, ^{235}U (kg)	277-4 can spacers,[d] ^{235}U (kg)
Solid HEU metal or alloy (specified geometric shapes)[e]	Cylinder A	≤ 100%	0.0	15	25.000
	Cylinder B	≤ 100%	0.0	18	30.000
	Square bars	≤ 100%	0.0	18	30.000
	Slugs	> 80%	0.0	18.286	25.601
	Slugs	≤ 80%	0.0	18.286	29.333
	Slugs	≤ 95%	0.4	Can spacers req'd[d]	34.766
Broken HEU metal or alloy		> 95%, ≤ 100%	0.0	Can spacers req'd	2.774
			0.4	Can spacers req'd	5.549
			0.8	Can spacers req'd	9.248
			2.0	Can spacers req'd	13.872
			3.2	Can spacers req'd	24.969
		> 90%, ≤ 95%	0.0	Can spacers req'd	3.516
			0.4	Can spacers req'd	6.154
			0.8	Can spacers req'd	10.549
			2.0	Can spacers req'd	18.461
			3.2	Can spacers req'd	26.373
		> 80%, ≤ 90%	0.0	Can spacers req'd	3.333
			0.4	Can spacers req'd	7.500
			0.8	Can spacers req'd	12.500
			2.0	Can spacers req'd	20.000
			3.2	Can spacers req'd	28.334
		> 70%, ≤ 80%	0.0	2.967	4.450
			0.4	5.192	8.900
			0.8	8.900	16.317
			2.0	17.059	25.218
			3.2	27.692	28.184
		> 60%, ≤ 70%	0.0	3.249	5.198
			0.4	5.848	12.996
			0.8	13.646	20.793
			2.0	21.444	24.692
			3.2	24.692	24.692
		≤ 60%	0.0	5.576 kgU	11.154 kgU
			0.4	14.872 kgU	28.813 kgU
			0.8	28.814 kgU	35.320 kgU
			2.0	35.320 kgU	35.320 kgU
			3.2	35.320 kgU	35.320 kgU
HEU oxide		> 20%, ≤ 100%	0.0	21.124[f]	Spacer not req'd
HEU skull oxide		> 20%, ≤ 100%	0.0	15.675	Spacer not req'd
UNX crystals [a,g]		> 20%, ≤ 100%	0.0	3.768	Spacer not req'd
UNX crystals [a,g]		> 20%, ≤ 100%	0.4	11.303[f]	Spacer not req'd
TRIGA fuel		70 %	0.0	0.408	Spacer not req'd

[a] HEU in solution form is not permitted for shipment in the ES-3100.
[b] All limits are expressed in kg ^{235}U unless otherwise indicated.
[c] Mass loadings cannot be rounded up.
[d] 277-4 can spacers as described on Drawing No. M2E801580A026 (Appendix 1.4.8).
[e] Geometries of solid shapes are as follows:
- Cylinder A is larger than 3.24 in. diameter but no larger than 4.25 in. diameter; maximum of 1 cylinder per can.

Table 1.3. Authorized content [a] and fissile mass loading limits [b,c] for ground transport (cont.)

- Cylinder B is no larger than 3.24 in. diameter: maximum of 1 cylinder per can.
- Square bars are no larger than 2.29 in. × 2.29 in. (cross section): maximum of 1 bar per can.
- Slugs are a maximum of 1.5 in. diameter × 2.0 in. tall: a maximum of 10 per convenience can where the actual number permitted is restricted by the stated loading limit.

[f] This ^{235}U fissile mass limit corresponds to 24 kg of material.

[g] UNX (where X ≤ 6). Must be shipped in a non-metallic convenience container (such as Teflon or polyethylene).

1.2.3.4 Shipping configurations

Authorized content convenience containers for the ES-3100 are cans constructed of stainless steel, tin-plated carbon steel, or nickel-alloy (series 200, passivated), and polyethylene and Teflon convenience bottles. These are used to hold the HEU contents for shipment in the ES-3100 package and to assure that the inside of the containment vessel does not become contaminated with HEU under NCT. Convenience containers used in the ES-3100 package must have an outer diameter less than or equal to 12.7 cm (5 in.). The height can vary up to the full internal height of the containment vessel or 78.74 cm (31 in.). Some contents require the use of can spacers (see Table 1.3). These can spacers are thin-walled stainless-steel cans filled with 277-4 material (Drawing M2E801580A026, Appendix 1.4.8). Each convenience can and spacer may be equipped with a stainless-steel band and nylon-coated wire to facilitate loading and unloading operations. Silicone rubber pads may also be used between convenience cans to dampen vibration and minimize contact between metal components. Any combination of convenience containers will be allowed in a single package, as long as the total height of the stack-up (including spacers, if required) does not exceed the inside working height of the containment vessel [78.74 cm (31 in.)]. If can spacers are required, no more than one-third of the total HEU content mass limit shown in Table 1.3 may be placed between any two spacers.

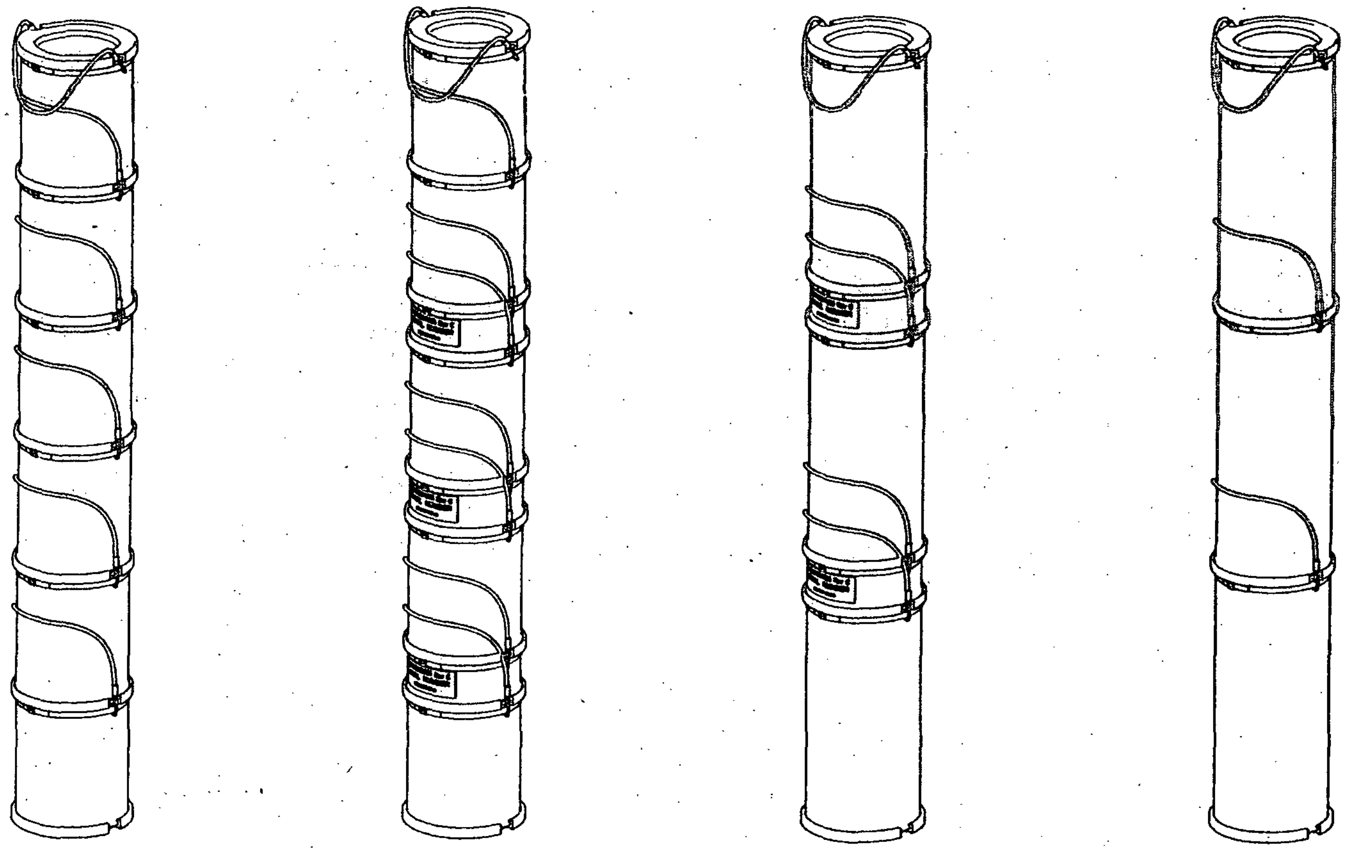
Typical configurations of authorized ES-3100 convenience containers are shown in Fig. 1.4. The shipping configurations shown in Fig. 1.4 utilize 3.00 and 4.25-in.-diameter convenience cans of various heights (such as 4.75, 4.88, 8.75, and 10 in.), 4.94 in. diameter by 8.7 in. tall polyethylene bottles, and 4.69 in. diameter by 9.4 in. tall Teflon bottles. Although any combination of the convenience cans that will fit inside the internal volume of the containment vessel may be used, content forms shall not be mixed in a single package (i.e., HEU oxides may not be packed with HEU metal). Empty cans and/or stainless-steel scrubbers may be used to fill the void space at the top of the containment vessel. If empty cans are shipped, a minimum 0.32-cm (0.125-in.)-diam hole must be placed through the lid to prevent over-pressurization of the can in the event of a thermal accident. In addition, these empty cans must be placed on top of the loaded cans. In configurations not requiring can spacers for criticality control, can spacers may be shipped for convenience if placed on top of loaded cans in the containment vessel. The HEU contents may be bagged or wrapped in polyethylene, and the convenience containers may also be wrapped in polyethylene to further reduce the possibility of contamination. The mass limit for all packing materials in a containment vessel – that can off-gas – (e.g., polyethylene, Teflon, silicone) is 1500 g. In some shipping configurations, silicone rubber pads will be placed between the convenience cans to reduce vibration.

1.2.3.5 Maximum normal operating pressure

As defined in 10 CFR 71.4, the maximum normal operating pressure is the maximum gauge pressure that would develop in the containment system in one year under an ambient temperature of 38°C (100°F) in still air, with appropriate insolation in the absence of venting, external cooling by an ancillary system, or operational controls during transport. Under these conditions, the maximum normal operating pressure in the ES-3100 containment vessel would be 122.63 kPa (17.786 psia). In comparison, the design internal pressure of the containment vessel is 801.17 kPa (116.2 psia). The design internal pressure is a conservatively assumed value that was assigned for the purpose of the ASME code calculations in Appendix 2.10.1.

1.2.3.6 Maximum and minimum weight

The maximum gross shipping weight for the ES-3100 package is 190.5 kg (420 lb). The proposed



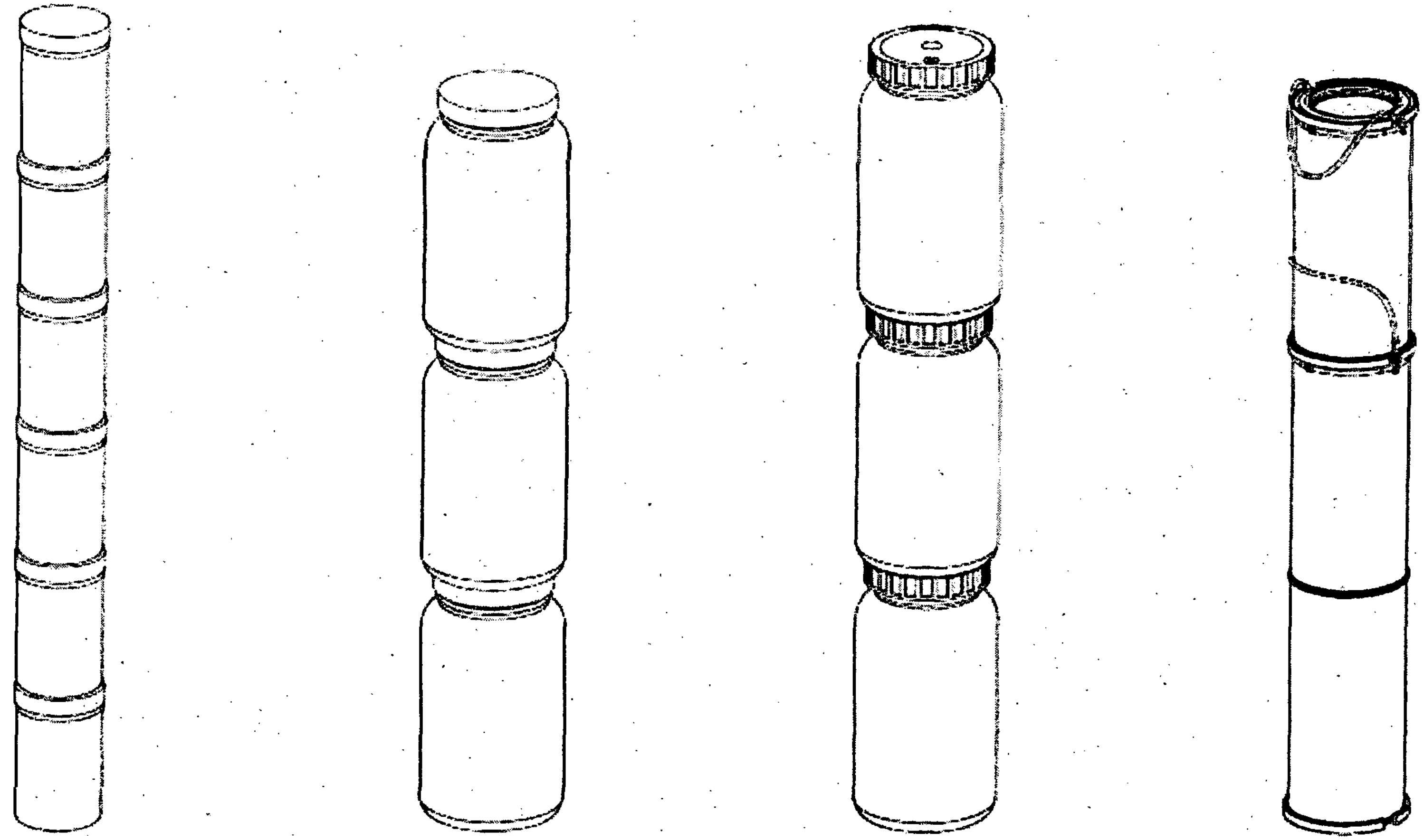
Six Cans
⌀4.25" × 4.88" Tall

Five Cans
⌀4.25" × 4.88" Tall
& three spacers
(one empty can)

Three Cans
⌀4.25" × 8.75" Tall
& two spacers

Three Cans
⌀4.25" × 10" Tall
⌀4.25" × 8.75" Tall

Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel.



Six Nickel Cans
⌀3.0" × 4.75" Tall

Three Poly Bottles
⌀4.94" × 8.7" Tall

Three Teflon Bottles
⌀4.69" × 9.4" Tall

One Can
⌀4.25" × 17.5" Tall
& one empty can

Fig. 1.4. Typical shipping configurations inside the ES-3100 containment vessel (continued).

maximum gross shipping weight of the ES-3100 package with any proposed content is 187.81 kg (414.05 lb) [Table 2.8]. The total weight of the tested ES-3100 units ranged from 157.4 to 203.7 kg (347 to 449 lb) [Table 2.9].

The weight of HEU contents in the ES-3100 shipping package is limited to 35.2 kg (77.60 lb). This limit has been established as a bounding case for the maximum structural, thermal, and containment limit for the package. A minimum HEU content weight of 2.77 kg (6.11 lb) has been established as the lower bounding case for the maximum structural, thermal, and containment limit for the package. This minimum content weight corresponds to the lowest simulated payload weight used during the prototype testing of the ES-3100 package. Actual mass restrictions for the various contents based on the criticality analyses are listed in Table 1.3. The maximum allowable payload weight of any configuration, including packing components (convenience cans and bottles, polyethylene bags, silicone pads, can spacers, etc.), is 40.82 kg (90 lb). The maximum weight of off-gassing material in the containment vessel for any shipping configuration (polyethylene bags and bottles, Teflon bottles, silicone pads) is limited to 1500 g. ES-3100 shipping package weights are discussed in greater detail in Sect. 2 and are broken down into individual component weights in Tables 2.8 and 2.9.

The payload weight (including convenience cans, silicone rubber pads, can spacers, and the HEU mockup) used in the ES-3100 package tests ranged from a minimum of 3.6 kg (8 lb) to a maximum of 50.3 kg (111 lb).

1.2.3.7 Maximum decay heat

As shown in Sect. 3.1.2 , the conservatively calculated maximum heat generation rate of the contents is approximately 0.4 W. The ES-3100 package was designed for a maximum heat load of 20 W. Thermal analyses have been performed assuming heat sources of 0.4, 20, and 30 W in the ES-3100 containment vessel (Appendix 3.6.2).

1.2.3.8 Loading restrictions

Loading restrictions based upon the results of the criticality safety calculations presented in Sect. 6.2.4 and additional limitations on packing materials outlined in Sect. 3 are as follows:

(1) HEU fissile material to be shipped in the ES-3100 package must be placed in stainless-steel, tin-plated carbon steel or nickel alloy convenience cans, polyethylene bottles, or Teflon bottles. Convenience containers used in the ES-3100 package must have an outer diameter less than or equal to 12.7 cm (5 in.). The height can vary up to the full internal height of the containment vessel or 78.74 cm (31 in.). Any closure on the convenience can is allowed.

(2) Any combination of convenience cans is allowed in a single package, as long as the total height (including silicone rubber pads and can spacers, if required) does not exceed the inside working height of the containment vessel (approximately 31 in.).

(3) In situations where empty convenience cans are shipped in the package, they must be placed on top of the loaded cans, and a minimum 0.32-cm (0.125-in.)-diam hole must be placed through the lid to prevent over pressurization of the can.

(4) The concentration of uranium isotopes in the content is limited as shown in Table 1.1.

(5) For pyrophoric considerations, HEU metal or alloy pieces must have a specific area not greater than 1 cm^2/g or must not pass through a 3/8-in. mesh sieve (or 0.95 cm). Incidental small pieces that do

not pass the size restriction tests, and powders, foils, turnings, and wires, may only be shipped if they are in a sealed, inerted container.

(6) The content shall not exceed "per package" fissile material mass loading limits specified in Table 1.3 based on the CSI. Where can spacers are required for a "per package" mass loading, the quantity of fissile material located in any vacancy between or adjacent to can spacers shall not exceed one-third of the mass loading limit in Table 1.3.

(7) The package content is defined as the HEU fissile material, the convenience cans and can spacers, and the associated packing materials (plastic bags, pads, tape, etc.) inside the ES-3100 containment vessel.

(8) The mass of packing materials and bottles that off-gas (i.e., polyethylene bagging and bottles, Teflon bottles, silicone rubber, etc.) used inside the ES-3100 containment vessel is limited to 1500 g (Sect. 3.1.4.1). This mass does not include moisture in oxide. Moisture is accounted for in criticality safety calculations (page 6-2).

1.2.4 Operational Features

The ES-3100 package is a Type B fissile material package designed in accordance with DOT and NRC regulations.. These regulations require that the package be operated without undue risk to the public, even in the event of a severe accident, and that the dose rate and nonfixed radioactive contamination on the external surface of the package conform with 49 CFR 173.441 and 173.443, respectively. These requirements are translated into the designs for the containment, shielding, and nuclear criticality safety of the contents when subjected to NCT and HAC. Designs for containment, shielding, and nuclear subcriticality safety are supported by operational procedures for loading, unloading, and refurbishing to ensure that those design features are used and maintained in a manner commensurate with their intended function. Drop tests, crush tests, puncture tests, thermal tests, and water immersion tests (Sects. 2.6 and 2.7) show that the drum assembly maintains the insulation and the containment vessel in their intended configurations when subjected to NCT and HAC.

The decay heat generated by the contents (maximum of approximately 0.4 W) is negligible for a package of this size (Sect. 1.2.3.7 and Sect. 3.1.2).

Design features that provide shielding, containment, and nuclear criticality control perform these functions in a passive manner. No valves, connections, gauges, active coolants, or operationally pressurized parts are integral to the ES-3100 package.

1.3 GENERAL REQUIREMENTS FOR ALL PACKAGES

This section demonstrates compliance with 10 CFR 71.43(a) and (b), "General Standards for All Packages."

1.3.1 Minimum package size

Requirement. The smallest overall dimension of a package may not be less than 10 cm (4 in.).

Analysis. The drum's outside diameter (including the chimes or rolling rings) is 49.2 cm (19.37 in.), and the outside height including the lid is 110.49 cm (43.5 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 (32.4 in.). Therefore, the packaging meets this requirement.

1.3.2 Tamper-indicating feature

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

Analysis. The removable drum head is attached to the body by eight 5/8-11-UNC-2B silicon bronze nuts and 5/8-in. nominal washers. Two 0.51-cm (0.20-in.)-thick lugs with 0.953-cm (0.375-in.)-diam holes project through slots in the drum lid and provide attachment for wire-type 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 seal is only required when HEU is in the package. It is not required for empty shipments.

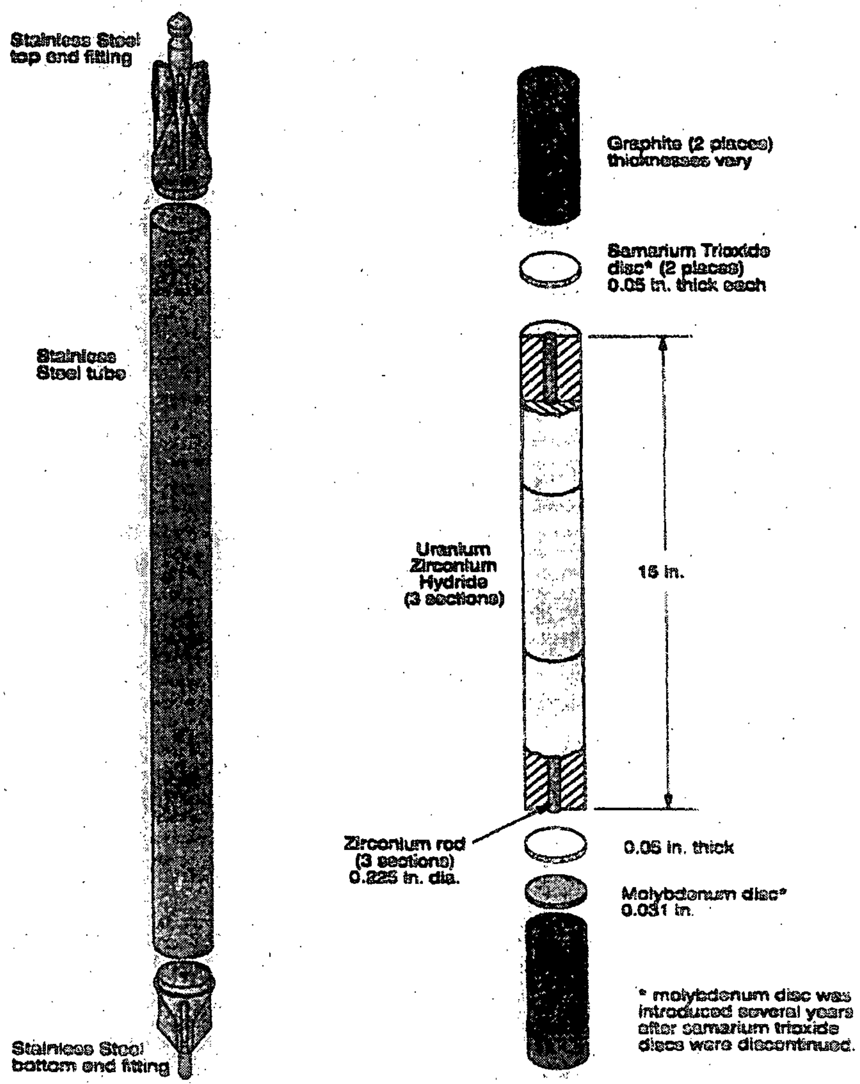


Fig 1-5. TRIGA Fuel Element.

Table 1.4. TRIGA Fuel Specifications

Uranium Content/Cladding/Type	Fuel Properties U (wt% of fuel)	U235 (wt% of U)	Active Fuel Length (in.)	Fuel OD (in.)	U (grams)	U235 (grams)	Hydrogen to Zirc Ratio
STANDARD ELEMENTS							
8.5 wt% aluminum clad element, 15 inch	8.5	20	15.00	1.41	189	37	1.0
8.5 wt% stainless steel clad element	8.5	20	15.00	1.44	197	39	1.6
12 wt% stainless steel, smooth clad element	12	20	15.00	1.44	285	56	1.6
12 wt% stainless steel, dimpled clad element	12	20	15.00	1.40	271	53	1.6
8.5 wt% stainless steel clad, High Enriched Uranium	8.5	70	15.00	1.44	194	136	1.6
20 wt% stainless steel clad element	20	20	15.00	1.44	503	99	1.6
30 wt% stainless steel clad element	30	20	15.00	1.44	825	163	1.6
45 wt% stainless steel clad element	45	20	15.00	1.44	1560	307	1.6
INSTRUMENTED ELEMENTS							
8.5 wt% aluminum clad element, 15 inch	8.5	20	15.00	1.41	189	37	1.6
8.5 wt% instrumented, stainless steel clad element	8.5	20	15.00	1.44	197	39	1.6
12 wt% instrumented, stainless steel, smooth clad element	12	20	15.00	1.44	285	56	1.6
12 wt% instrumented, stainless steel, dimpled clad element	12	20	15.00	1.40	271	53	1.6
8.5 wt% instrumented stainless steel clad, High Enriched Uranium	8.5	70	15.00	1.44	194	136	1.6
20 wt% instrumented, stainless steel clad element	20	20	15.00	1.44	503	99	1.6
30 wt% instrumented, stainless steel clad element	30	20	15.00	1.44	825	163	1.6
45 wt% instrumented stainless steel clad element	45	20	15.00	1.44	1560	307	1.6
FUELED FOLLOWER CONTROL RODS							
8.5 wt% stainless steel clad fueled follower control rod	8.5	20	15.00	1.31	163	32	1.6
12 wt% stainless steel, smooth clad fueled follower control rod	12	20	15.00	1.31	237	47	1.6
12 wt% stainless steel, dimpled clad fueled follower control rod	12	20	15.00	1.40	257	50	1.6
12 wt% stainless steel, dimpled clad fueled follower control rod	12	20	15.00	1.40	271	53	1.6
8.5 wt% stainless steel high enriched fueled follower control rod for a cluster rod assy	8.5	70	15.00	1.31	162	113	1.6
20 wt% stainless steel clad fueled follower control rod	20	20	15.00	1.31	418	82	1.6
30 wt% stainless steel clad fueled follower control rod	30	20	15.00	1.31	685	135	1.6
45 wt% stainless steel clad fueled follower control rod	45	20	15.00	1.31	1560	307	1.6
STANDARD RODS FOR CLUSTER ASSEMBLY							
8.5 wt% stainless steel clad cluster rod	8.5	20	15.00	1.37	166	33	1.6
12 wt% stainless steel, smooth clad cluster rod	12	20	15.00	1.37	243	58	1.6
8.5 wt% stainless steel clad, High Enriched Uranium, cluster rod	8.5	70	15.00	1.37	175	122	1.6
20 wt% stainless steel clad cluster rod	20	20	15.00	1.37	427	85	1.6
30 wt% stainless steel clad cluster rod	30	20	15.00	1.37	710	141	1.6
8.5 wt% stainless steel clad, HEU, fueled follower control rod	8.5	70	15.00	1.31	160	112	1.6
45 wt% stainless steel clad fueled follower control rod	45	20	15.00	1.37	1348	267	1.6

1.4 APPENDICES

Appendix	Description
1.4.1	PACKAGE CERTIFICATION DRAWING
1.4.2	EQUIPMENT SPECIFICATION JS-YMN3-801580-A002, *Rev D, ES-3100 DRUM ASSEMBLY*
1.4.3	EQUIPMENT SPECIFICATION JS-YMN3-801580-A001, *Rev E, ES-3100 CONTAINMENT VESSEL*
1.4.4	EQUIPMENT SPECIFICATION, JS-YMN3-801580-A003, *Rev C, MANUFACTURING PROCESS SPECIFICATION FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE*
1.4.5	EQUIPMENT SPECIFICATION, JS-YMN3-801580-A005, *Rev F, CASTING CATALOG NO. 277-4 NEUTRON ABSORBER FOR THE ES-3100 SHIPPING PACKAGE*
1.4.6	PACKAGE CATEGORY DETERMINATION
1.4.7	HEU OXIDE MATERIAL SPECIFICATION AS PROVIDED BY Y-12 HIGHLY ENRICHED URANIUM DISPOSITION PROGRAM OFFICE
1.4.8	PACKAGE ENGINEERING DRAWINGS
1.4.9	DESIGN ANALYSES AND CALCULATIONS, MIXING WEIGHTS AND ELEMENTAL COMPOSITION OF 277-4 NEUTRON POISON USED IN THE ES-3100
1.4.10	PYROPHORICITY OF URANIUM METAL

APPENDIX 1.4.1

PACKAGE CERTIFICATION DRAWING

Drawing No.	Rev.	Title
M2E801580A037	B	ES-3100 Shipping Container, Consolidated Assembly Drawing

NOTES

1. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
2. DIMENSIONS ARE IN INCHES [mm].
3. APPROXIMATE WEIGHT: 325 LBS [147.4 Kg] FOR F/N 1 EMPTY.
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

[5] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002 ES-3100 DRUM ASSEMBLY.

[6] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A001 ES-3100 CONTAINMENT VESSEL.

[7] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 MANUFACTURING PROCESS SPECIFICATION FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE.

[8] SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 CASTING CATALOG # 277-4 NEUTRON ABSORBER FOR THE ES-3100 SHIPPING PACKAGE.

[9] DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE

[10] DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.

NOTE	QTY REQ'D	NOMENCLATURE OR DESCRIPTION	MATERIAL / SPECIFICATION	SHEET NO	FIND NO
10	AR	KRYTOX #240AC OR EQUAL THREAD LUBRICANT	FLUORINATED GREASE MILLER-STEPHENSON CHEMICAL CO.	NA	18
9	AR	SUPER-O-LUBE OR EQUAL O-RING LUBRICANT	CLEAR DIMETHYL SILOXANE POLYMER PARKER HANNIFIN CORP	NA	17
	1	MODIFIED VCO THREADED PLUG	BRASS	5	16
	1	EXTERNAL RETAINING RING	302 SST	5	15
	1	PLUG PAD	SILICONE RUBBER 22±5 SHORE A COLOR BLACK/GRAY	2	14
	1	CV FLANGE PAD		2	13
	1	CV BOTTOM PAD		2	12
	1	OUTER O-RING Ø5.859±.035 ID X Ø.139 ±.004	ETHYLENE PROPYLENE 70±5 SHORE A COLOR BLACK	2	11
	1	INNER O-RING Ø5.359±.035 ID X Ø.139±.004		2	10
5	1	ES3100 DATA PLATE	16 GA 304/304L SST ASTM SA240	2	9
5	1	ES3100 TREFOIL DATA PLATE		2	8
6	1	CONTAINMENT VESSEL CLOSURE NUT	NITRONIC 60 SST ASME SA-479 UNS-S21800	5	7
6	1	CONTAINMENT VESSEL SEALING LID	304 SST ASME SA-479	5	6
6	1	CONTAINMENT VESSEL BODY	304L SST	5	5
7 5	1	TOP PLUG WELDMENT	16 GA 304/304L SST ASTM SA240	4	4
5	1	DRUM LID WELDMENT		3	3
8 7 5	1	DRUM WELDMENT		3	2
	X	MAIN ASSEMBLY		2	1
	← NEXT ASSEMBLY		PARTS LIST		

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	10/16/06	J.F. DECLUE

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date 10/11/06

THIS DRAWING PRODUCED ON PRO/ENGINEER

REV	DESCRIPTION		
B	REVISED TREFOIL DATA PLATE, F/N 8		
A	PAGE 1: MODIFIED GENERAL NOTES AND UPDATED FIELD NOTES ADDED TOLERANCES TO ORINGS. PAGE 3: ADDED CORRECT TOLERANCES AND REF. DIMS. PAGE 4. ADDED CORRECT INSPECTION DIMS. AND WELD SYMS. PAGE 5. ADDED CORRECT TOLERANCES AND INSPECTION DIMS. AND ADDED NOTE TO -5 ADDED SHEET 6 RN Y2003-0328		
0	RN: Y2003-0328 ORIGINAL ISSUE		

SCALE: N.T.S.

TOLERANCES UNLESS OTHERWISE SPECIFIED: FRACTIONS; XX DECIMALS ±.03; XXX DECIMALS ±.010; ANGLES ±0.5°; BREAK SHARP EDGES .03 MAX; FINISH 125 RMS

DRAWING APPROVALS: JM RAY; G MCGINNIS; GA BYINGTON; RB CONATSER; ML GOINS; RD AIGNER; JG ARBITAL

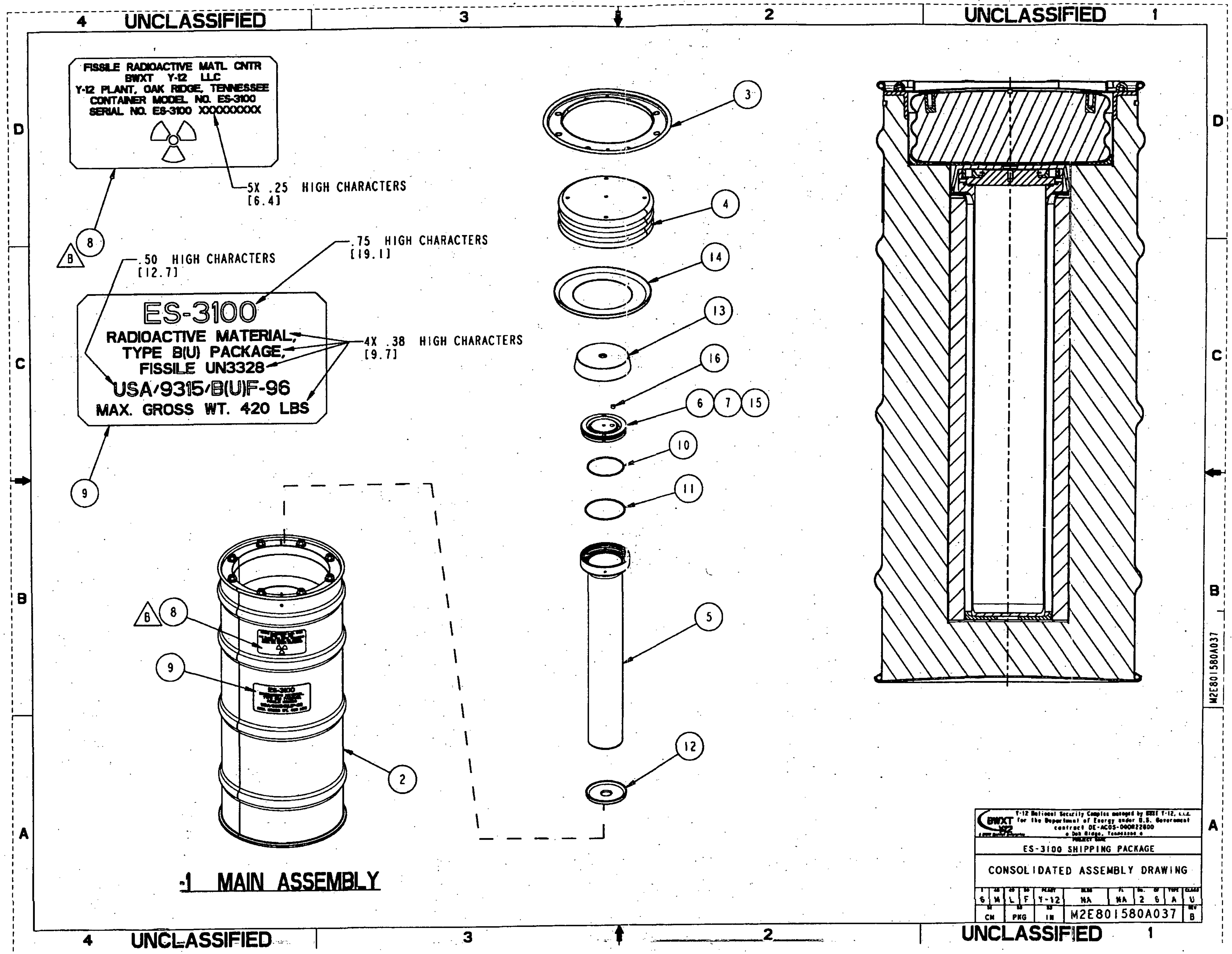
Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800, Oak Ridge, Tennessee

ES-3100 SHIPPING PACKAGE

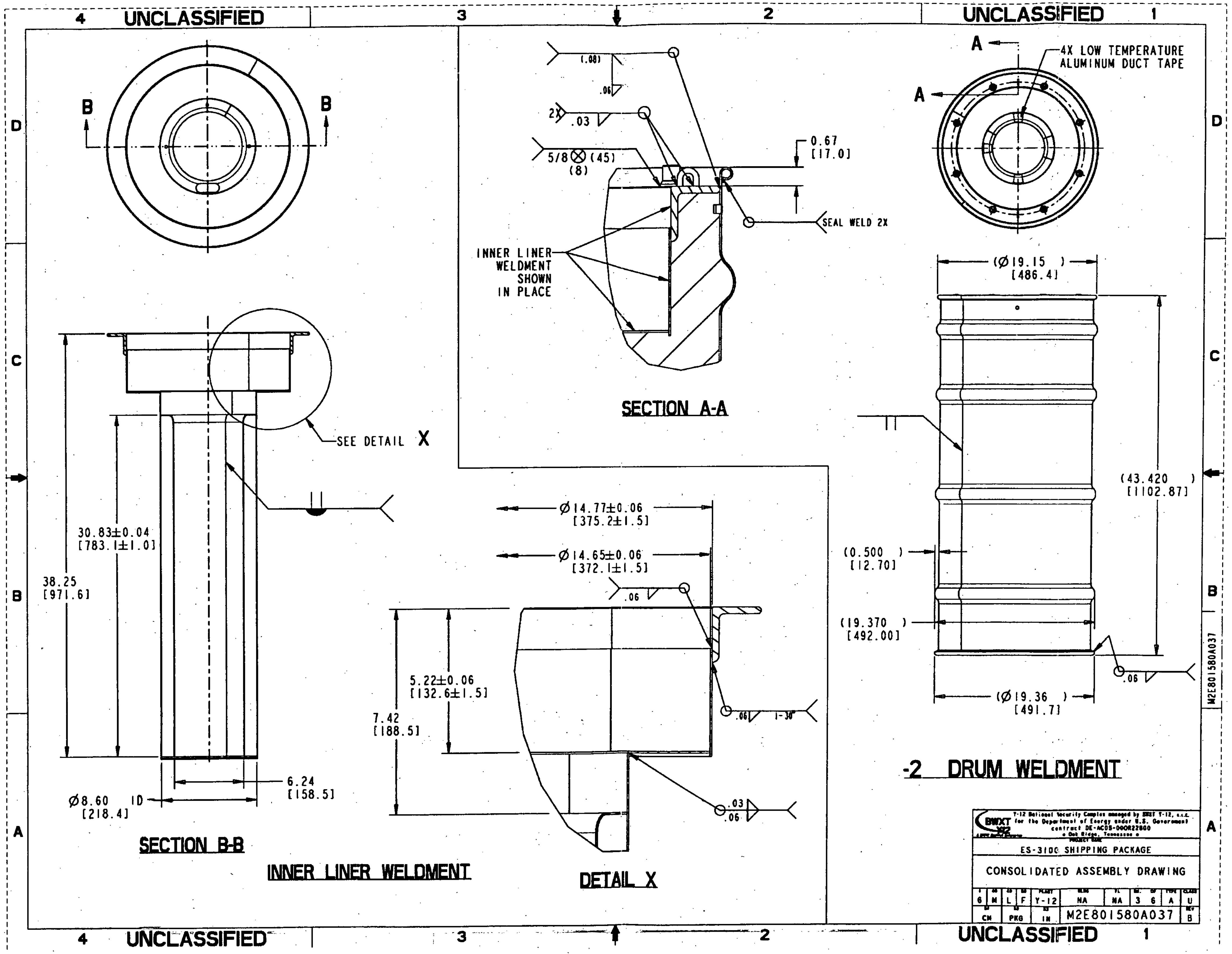
CONSOLIDATED ASSEMBLY DRAWING

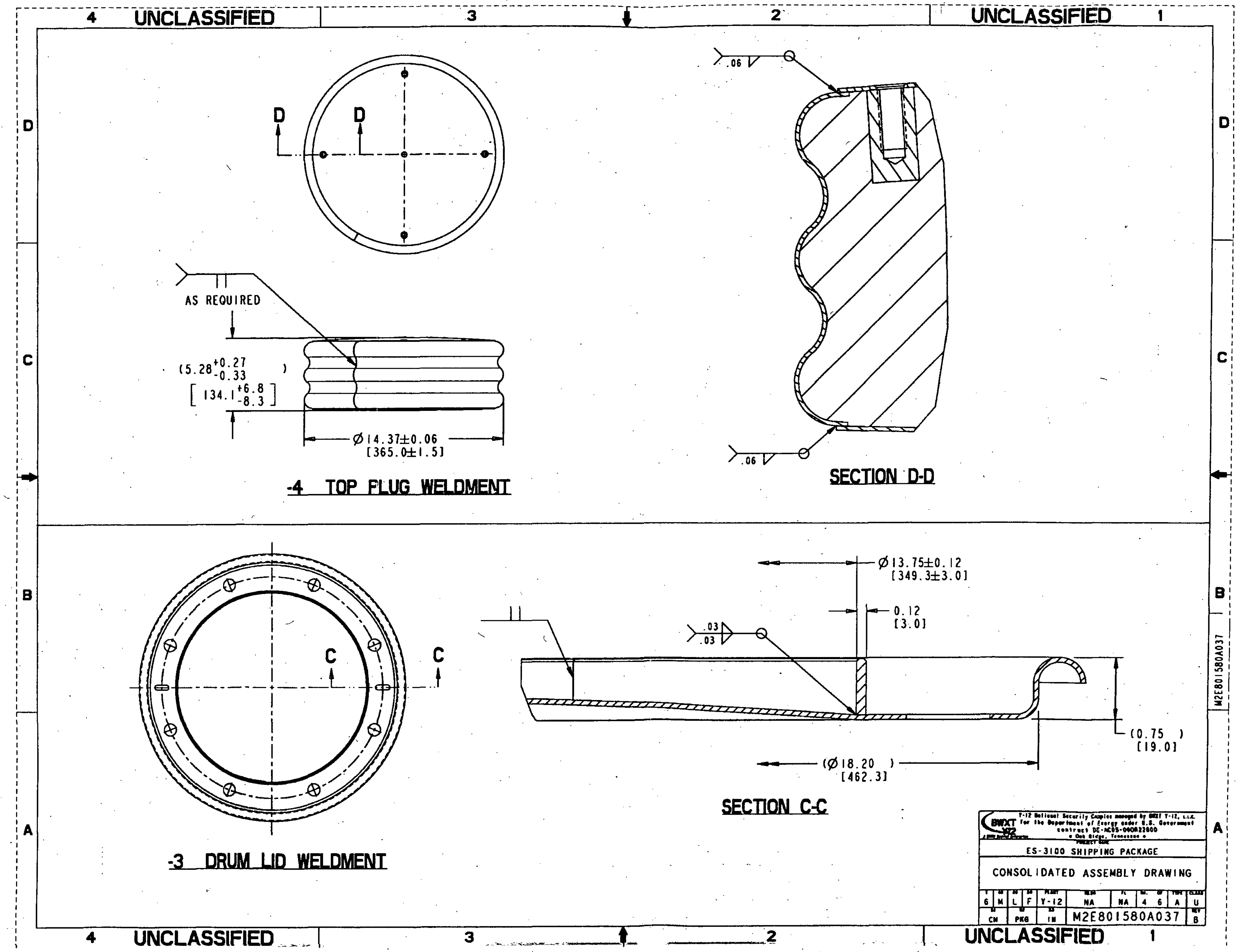
6 M L F Y-12 NA NA 1 6 A U

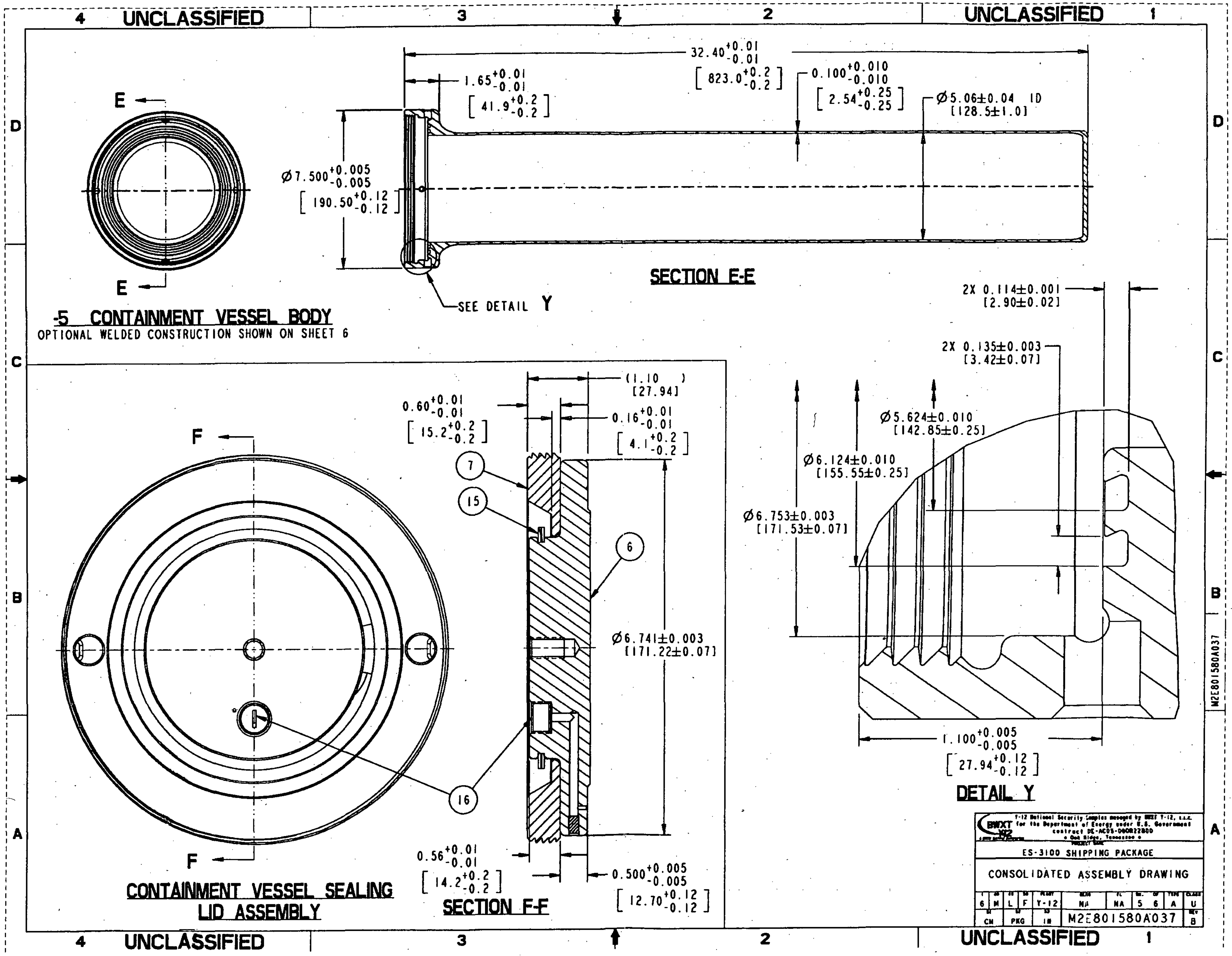
M2E801580A037 REV B



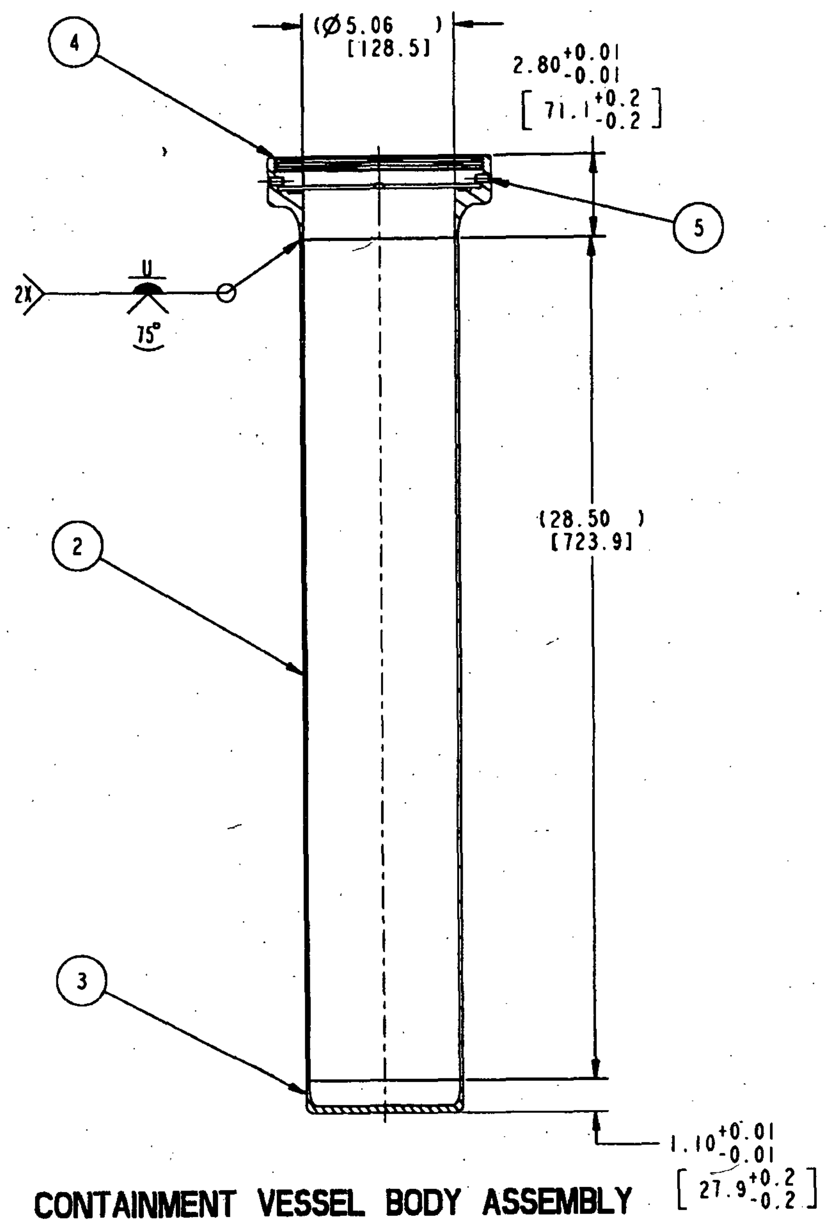
UNCLASSIFIED
FISSILE RADIOACTIVE MATL CNTR
BWXT Y-12 LLC
Y-12 PLANT, OAK RIDGE, TENNESSEE
CONTAINER MODEL NO. ES-3100
SERIAL NO. ES-3100 XXXXXXXXX
5X .25 HIGH CHARACTERS [6.4]
.75 HIGH CHARACTERS [19.1]
.50 HIGH CHARACTERS [12.7]
ES-3100
RADIOACTIVE MATERIAL,
TYPE B(U) PACKAGE,
FISSILE UN3328
USA/9315/B(U)F-96
MAX. GROSS WT. 420 LBS
4X .38 HIGH CHARACTERS [9.7]
-1 MAIN ASSEMBLY
M2E801580A037
ES-3100 SHIPPING PACKAGE
CONSOLIDATED ASSEMBLY DRAWING
UNCLASSIFIED


UNCLASSIFIED
4
3
2
1
D
C
B
A
B
B
SEE DETAIL X
30.83±0.04
[783.1±1.0]
38.25
[971.6]
6.24
[158.5]
Ø8.60 ID
[218.4]
SECTION B-B
INNER LINER WELDMENT
(.08)
.06
2X .03
5/8 (45)
(8)
0.67
[17.0]
SEAL WELD 2X
INNER LINER WELDMENT SHOWN IN PLACE
SECTION A-A
Ø14.77±0.06
[375.2±1.5]
Ø14.65±0.06
[372.1±1.5]
.06
5.22±0.06
[132.6±1.5]
7.42
[188.5]
.06
1-30
.03
.06
DETAIL X
A
A
4X LOW TEMPERATURE ALUMINUM DUCT TAPE
(Ø19.15)
[486.4]
(43.420)
[1102.87]
(0.500)
[12.70]
(19.370)
[492.00]
.06
(Ø19.36)
[491.7]
-2 DRUM WELDMENT
M2E801580A037
BWXT Y-12
ES-3100 SHIPPING PACKAGE
CONSOLIDATED ASSEMBLY DRAWING
6 M L F Y-12 NA NA 3 6 A U
CH PRG IN M2E801580A037 B


UNCLASSIFIED
D
D
AS REQUIRED
(5.28+0.27 -0.33)
[134.1+6.8 -8.3]
Ø14.37±0.06
[365.0±1.5]
-4 TOP PLUG WELDMENT
.06
.06
SECTION D-D
C
C
-3 DRUM LID WELDMENT
Ø13.75±0.12
[349.3±3.0]
0.12
[3.0]
.03
.03
(0.75)
[19.0]
(Ø18.20)
[462.3]
SECTION C-C
ES-3100 SHIPPING PACKAGE
CONSOLIDATED ASSEMBLY DRAWING
M2E801580A037
UNCLASSIFIED



UNCLASSIFIED
-5 CONTAINMENT VESSEL BODY
OPTIONAL WELDED CONSTRUCTION SHOWN ON SHEET 6
SECTION E-E
SEE DETAIL Y
CONTAINMENT VESSEL SEALING LID ASSEMBLY
SECTION F-F
DETAIL Y
ES-3100 SHIPPING PACKAGE
CONSOLIDATED ASSEMBLY DRAWING
M2E801580A037
UNCLASSIFIED



CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION

WELD NOTES:

1. ALL WELDS ON THE CONTAINMENT VESSELS SHALL BE DONE EITHER BY THE GTAW OR GMAW PROCESS, MANUAL OR AUTOMATIC, AT THE DISCRETION OF THE SELLER UNLESS SPECIFICALLY CALLED OUT ON THE DRAWINGS. BACKING RINGS, EVEN IF REMOVED AFTER THE WELD HAS BEEN MADE, SHALL NOT BE USED. AS PREVIOUSLY STATED, WELD SYMBOLS ARE PROVIDED ON THE DRAWING INDICATING FOR EACH WELD THE TYPE OF WELD AND DIMENSIONS OF THE WELD.

2. EXCEPT AS LIMITED BY THIS SPECIFICATION, THE APPLICABLE REQUIREMENTS OF NB-4300 AND NB-4400 SHALL APPLY TO THE CONTAINMENT VESSEL.

3. PRIOR TO WELDING, ALL WELD PREPARATION AREAS AND THE SURFACES WITHIN ONE INCH OF THE WELD AREA SHALL BE EXAMINED VISUALLY AND WITH LIQUID PENETRANT. THE ACCEPTANCE CRITERIA FOR THESE EXAMINATIONS ARE THOSE STATED IN NB-5130 (A) THROUGH NB-5130 (D). THE RESULTS OF THESE SURFACE EXAMINATIONS SHALL BE REPORTED TO THE COMPANY TOGETHER WITH THE WELD EXAMINATION REPORTS, SEE SECTION 3.4 OF THIS SPECIFICATION.

4. WELDERS PERFORMING TWO OR MORE WELDS IN ONE DAY THAT ARE REJECTED BASED UPON WELDER TECHNIQUE SHALL BE SUBJECT TO BE RE-QUALIFIED TO THE APPROPRIATE WELDING PROCEDURES, SEE SECTION IX, PARAGRAPH QW-320 OF THE ASME CODE.

5. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, AND NB-5300 SHALL APPLY TO THE CONTAINMENT VESSELS. THE PLUG WELD SHOWN ON DRAWING M2E801580A015 SHALL BE EXAMINED VISUALLY AND WITH PENETRANT. THE APPLICABLE REQUIREMENTS IN PARAGRAPHS NB-5110, AND NB-5350 SHALL APPLY TO THE PLUG WELD. NOTE THAT THE REFERENCE TO THE INSPECTOR IN NB-5112, FOR THE PURPOSES OF THIS SPECIFICATION IS EITHER THE COMPANY'S INSPECTOR OR A SUBCONTRACTOR DESIGNATED BY THE COMPANY.

6. MATERIALS USED IN THE PENETRANT EXAMINATION OF WELDS AND IN THE FINAL SURFACE EXAMINATION OF FINISHED COMPONENTS (SEE SECTION 3.7) SHALL BE SPECIFICALLY RECOMMENDED BY THEIR SUPPLIERS FOR USE WITH AUSTENITIC STAINLESS STEELS, AND COPIES OF THE CERTIFICATION OF CONTAMINANT CONTENT OF MATERIALS USED (SEE SECTION V, ARTICLE 6, T-641) SHALL BE SUPPLIED TO THE COMPANY WITH THE EXAMINATION REPORTS.

7. REPAIR WELDING SHALL MEET THE APPLICABLE REQUIREMENTS OF NB-2500.

8. CERTIFIED WRITTEN WELD EXAMINATION REPORTS TOGETHER WITH THE CORRESPONDING MATERIAL SURFACE EXAMINATION REPORTS, AND WELD MAP SHALL BE SUBMITTED TO THE COMPANY AS STATED IN THE PROCUREMENT SPECIFICATION FOR THE ES-3100 CONTAINMENT VESSEL. WELD EXAMINATION REPORTS FOR ALL WELD AND SURFACE EXAMINATION SHALL INCLUDE: THE CONTAINMENT VESSEL SERIAL NUMBER, A WELD MAP SHOWING THE LOCATION OF THE WELD AND EXAMINATION AREA, THE WELDER'S NAME, THE EXAMINER S NAME, THE TIME AND DATE OF THE WELD EXAMINATION, THE EXAMINATION PROCEDURE(S) NUMBER USED, THE WPS NUMBER, THE HEAT NUMBERS OF THE MATERIALS JOINED, THE HEAT NUMBER OF THE WELD FILLER, AND EXAMINER S REMARKS. THE EXAMINER S REMARKS SHALL INCLUDE THE RESULTS OF THE EXAMINATION AND ACCEPTANCE, OR REJECTION OF THE WELD BASED ON THE STATED CRITERIA. ONE SET OF RADIOGRAPHS SHALL BE PROVIDED TO THE COMPANY WITH RADIOGRAPHIC EXAMINATION REPORTS. IF THE WELD OR SURFACE IS REJECTED, A DESCRIPTION OF THE DEFECT AND SKETCH SHOWING THE LOCATION SHALL BE PROVIDED.

9. IF A WELD IS REJECTED, THE AREA SHALL BE WELD REPAIRED BY THE SELLER AND RE-EXAMINED. AFTER TWO UNSUCCESSFUL REPAIR ATTEMPTS, THE COMPANY SHALL BE NOTIFIED FOR APPROVAL TO PERFORM MORE REPAIR ATTEMPTS. THE COMPANY MAY, AT ITS OPTION, CHOOSE TO REJECT FURTHER REPAIR EFFORTS AND REQUIRE THAT A REPLACEMENT PART BE FABRICATED.

2	-5	.2501/.2503 OD DOWEL PIN	ANSI B18.8.2 18-8-SST	5
1	-4	VESSEL FLANGE	ASME SA-182 TYPE F304L	4
1	-3	VESSEL END CAP	ASME SA-182 TYPE F304L	3
1	-2	VESSEL BODY SCH40 PIPE	ASME SA-182 TYPE F304L	2
X	-1	CONTAINMENT VESSEL WELDED ASSEMBLY		1
	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL/ SPECIFICATION	FIND NO
← QTY REQ'D NEXT ASSEMBLY			PARTS LIST	

Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 • Oak Ridge, Tennessee •

ES-3100 SHIPPING PACKAGE

CONSOLIDATED ASSEMBLY DRAWING

6	M	L	F	Y-12	NA	NA	6	6	A	U
CN		PKG		IN	M2E801580A037					B

M2E801580A037

APPENDIX 1.4.2

EQUIPMENT SPECIFICATION JS-YMN3-801580-A002, *ES-3100 DRUM ASSEMBLY*

EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO. JS-YMN3-801580-A002		REV. D	ISSUE DATE 10-15-03
PAGE i OF ii		REVISION DATE 03/15/06	
PROCURED BY BWXT L.L.C.		INSTALLED BY BWXT L.L.C.	
PROJECT TITLE ES-3100 Shipping Package	PLANT Y-12	BUILDING AREA	
JOB TITLE Design Definition	W.O. OR E.S.O. 7RCPCA5A	RECORD NUMBER 2003-0328	
SPECIFICATION FOR ES-3100 DRUM ASSEMBLY		SSC IDENTIFICATION NUMBER	

ENGINEERING AND PLANT APPROVALS

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY J.L. Heck	10-21-03	PROJECT ENGINEER M.R. Feldman	10-29-03
DISCIPLINE MANAGER J.C. Walls	10-29-03	OPERATIONS MANAGER/SYSTEM OWNER	
DESIGN VERIFICATION Roger Aigner	10-21-03		

REVISIONS/ENGINEERING AND PLANT APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issue Approved
B	Change the title of drawing M2E-801580-A001 from Confinement Boundary Assembly to Drum Assembly. Change the title this specification from ES-3100 Confinement Boundary Drums to ES-3100 Drum Assembly. Deleted reference to drawing M2E-801580-A009, Pad Details. Added the reference to drawings M2E-801580-A010, Data Plates and M2E-801580-A031, Main Assembly. Changed the wording in the first paragraph of Section 3.3
C	Revised the third paragraph of Section 3.0 in accordance with REDC PE-06-058.
D	Section 3.0, paragraph 3, the phrase "certifying authority's written approval" has been revised to "regulatory authority's written approval."

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY G. A Byington /s/	3/14/06	PROJECT ENGINEER J. Arbital /s/	3/14/06
DISCIPLINE MANAGER C. M. Amonett /s/	3/14/06	OPERATIONS MANAGER/SYSTEM OWNER	
DESIGN VERIFICATION Roger D. Aigner /s/	3/14/06		

This document has been has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner /s/ Date: 3/14/06

EXEMPT FROM IO-155

TABLE OF CONTENTS **PAGE**

LIST OF COMPANY DRAWINGS

Drawing Number	Title
M2E-801580-A001	Drum Assembly
M2E-801580-A002	Body Weldment
M2E-801580-A003	Inner Liner Weldment
M2E-801580-A004	Double Open Head Reinforced Drum
M2E-801580-A005	Misc. Details
M2E-801580-A006	Drum Lid Weldment
M2E-801580-A007	Drum Lid
M2E-801580-A008	Top Plug Weldment
M2E-801580-A010	Data Plates
M2E-801580-A031	Main Assembly

EQUIPMENT SPECIFICATION

ES-3100 DRUM ASSEMBLY

SPECIFICATION NO.	REV.
JS-YMN3-801580-A002	D
ISSUE DATE	REVISION DATE
10-15-03	3/15/06
PLANT	PAGE
Y-12	1 OF 5

1.0 SCOPE

This specification, the Procurement Specification for the ES-3100 Drum Assembly, specifications JS-YMN3-801580-A003 and JS-YMN3-801580-A005, the Company's drawings, and the referenced codes and standards in section 2.0 of this specification state the requirements for the procurement of materials and components, fabrication, inspection, examination, assembly, and testing of the Drum Assembly for the ES-3100 shipping package. If conflicting requirements appear between the Company's documents, and the standards listed in section 2.0 of this document, the Seller shall immediately notify the Company, so that these can be resolved. The Seller shall provide the number of completed assemblies specified in the purchase order.

This specification describes the applicable procedures to be followed in the fabrication, welding, examination, inspection, quality assurance, and documentation requirements for a Drum Assembly used in a Type B nuclear shipping package.

The Drum Assembly shall be manufactured in accordance with those paragraphs of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1 that are specified in this document. The Drum Assemblies are not pressure vessels and are not to be hydrostatically tested, nor are they to be stamped. If the Seller does not have certificate of authorization from the ASME to apply the U stamp, the Seller shall be familiar with, and capable of meeting those requirements in Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code that are referenced in this specification.

Company specification JS-YMN3-801580-A003 gives requirements for casting Kaolite, and JS-YMN3-801580-A005 gives requirements for casting Catalog No. 277-4 in the drum as shown on the Company's drawings.

2.0 APPLICABLE CODES AND STANDARDS

The Drum Assembly shall be fabricated, inspected, and tested according to the design drawings, and the portions of the codes, standards, and regulations to the extent described herein.

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section VIII, Division 1, 2001 Edition with 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Parts A and C, 2001 Edition and 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section V, 2001 Edition and 2002 and 2003 addenda

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section IX, 2001 Edition and 2002 and 2003 addenda

- American Society For Nondestructive Testing, No. SNT-TC-1A-1992, Recommended Practice for Nondestructive Testing Personnel Qualification and Certification, Dec 1992

- Military Standard, MS27683, Drum, Metal-Shipping and Storage 16 to 80 Gallons

- American Society For Testing Materials, ASTM A 380-99$^{\epsilon 1}$, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems.

All references to the ASME Code in this document are to the ASME Boiler and Pressure Vessel Code, the 2001 Edition with the 2002 and the 2003 addenda.

3.0 DETAILED REQUIREMENTS

Detailed dimensional requirements and the materials of construction are called out on the Company's drawings. Additional requirements for materials are given in section 3.1 of this specification. The Seller shall be responsible for determining stock sizes so that the finished machined components meet the dimensions, tolerances and surface features called out on the attached drawings.

Weld symbols are provided on the Company's drawings indicating for each weld the type of weld and dimensions of weld. Additional welding requirements are stated in section 3.2 of this specification

Any material substitution or any other deviation from the requirements shown on the Company's drawings, or stated in the Company's document is not permitted without the Seller submitting a written request for waiver or deviation, Company's written approval, and regulatory authority's written approval (see the Procurement Specification for the ES-3100 Drum Assembly).

The assembled Drum Assembly shall be marked according to the Company's drawings. The Company will assign permanent serial numbers for each Drum Assembly. Drum Assembly's records may be maintained based upon a temporary serial number assigned by the Seller. The temporary serial number for the Drum Assembly shall be cross-referenced to the Drum Assembly's permanent serial number.

The following additional requirements apply as follows:

3.1 Materials

Except for the weld studs, documented Certified Material Test Reports (CMTR's) shall be provided to the Company for all materials used in weldments for the fabrication of the Drum Assembly, including weld filler metal. The CMTR's shall be traceable to heat numbers and shall demonstrate compliance with the SA or SFA material specifications called out. For all other the materials documented Certificates of Compliance shall be provided to the Company certifying that the materials provided comply the requirements stated on the Company's drawings and specifications. See the Procurement Specification for the ES-3100 Drum Assembly for specific documentation requirements.

The markings on the weldment materials shall not be removed until after all weld examination is complete. Note that the heat numbers of base metals and weld filler are required on all weld examination reports (see section 3.3 of this specification).

The weld filler metal used in the fabrication of the Drum Assemblies shall be procured to comply with the SFA specifications of Section II, Part C of the ASME Code that are stated in the Seller's welding procedure specifications. Weld filler metal shall be procured traceable to heat numbers, and Certified Material Test Reports shall be furnished to the Company for each heat of weld wire filler. The control of weld filler by the Seller shall permit a weld examiner to be able to determine the heat number of the weld filler used in any weld on the Drum Assembly.

Prior written approval of the Company shall be obtained for any weld repair on materials, and the weld repair areas shall be noted in a sketch supplied with the CMTR for the material that was weld repaired. Note that depending on the specific defect in a specific material, the Company may or may not approve the weld repair, even if it is permitted by the material specification.

3.2 Welding

All welding shall be done in accordance with welding procedure specifications that are written and performance qualified in accordance with the ASME Code, Section IX. All welders shall be performance qualified to weld using these procedures, and their qualifications documented in accordance with the ASME Code, Section IX. The welding fabrication requirements stated in the ASME Code, Section VIII, Division 1, paragraphs UW-26 through UW-48 shall be met. The Inspector referenced in these paragraphs shall be an individual or individuals that are employed by the Company or subcontractors to the Company.

All butt welds in rolled sheet, pipe and angle joints shall be full penetration butt welds. With the exception of the seam welds in the drum body, all welds shall be done by the GTAW, GMAW, PAW or a Capacitive Discharge (CD) stud welding process.

Welders performing two or more welds in one day that are rejected shall be subject to be re-qualified to the appropriate welding procedures, see Section IX, and paragraph QW-320 of the ASME Code.

3.3 Weld Examination

A qualified weld examiner using a written weld examination procedure shall visually examine all designated welds. Weld examiners shall be qualified to perform visual weld inspection in accordance with their employer's written practice, which must be in accordance with either SNT-TC-1A (2001 Edition), "Personnel Qualification and Certification in Nondestructive Testing;" or ANSI/ASNT CP-189 (2001 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" published by the American Society for Nondestructive Testing. The weld examination procedure shall meet the requirements of the ASME Code, Section V. The weld examination procedures, the weld examiners qualifications, and the weld examination reports shall be submitted to the Company.

Written weld examination reports for all weld examination shall include: the Drum Assembly serial number, a weld map showing the location of the weld, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure number used, the WPS number, the heat numbers of the materials joined, the heat number of the weld filler, and the examiner's remarks. The examiner's remarks shall include the results of the examination, and acceptance or rejection of the weld based on the stated criteria and include a description and sketch showing the location of any defects found. Weld examination reports shall be submitted to the Company as stated in the Procurement Specification for the ES-3100 Drum Assembly.

The acceptance criteria for joint fit-up and alignment, and for visual examination of welds are given in the ASME Code, Section VIII, Division 1, paragraphs UW-31 through UW-36. In addition, any visible defects such as lack of fusion, lack of penetration, linear or crack like defects, and visible porosity, shall be cause for rejection.

If a weld is rejected, the area may be weld repaired by the Seller and re-examined. After two unsuccessful repair attempts, the Company shall be notified for approval to perform more repair attempts. The Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

If penetrant examination of welds or materials is performed the materials used in the examination shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used (see Section V, Article 6, T-641) shall be supplied to the Company with the examination reports.

3.4 Cleaning and Passivation

Cleaning procedures for the stainless steel, including weld areas, shall be submitted to the Company for approval prior to the start of fabrication, see the Procurement Specification for the ES-3100 Drum Assembly. Only non-chloride bearing chemicals shall be used for cleaning (such as trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 0.5 parts per million.

Finished components awaiting assembly and assemblies shall be free of dirt, debris, foreign objects, cutting fluids, metal chips, grinding residue, and other foreign substances. The Seller shall clean, cover, and protect parts and subassemblies from becoming dirty while in storage, and to the extent practical, in the shop environment while in work.

After final machining and examination of all welds except the attachment welds for the drum bottom and the closure weld on the top plug, and prior to filling with Kaolite and Catalog No. 277-4 (see JS-YMN3-801580-A003 and JS-YMN3-801580-A005), clean and passivate all stainless steel surfaces of the Drum Assembly in accordance with ASTM A 380. After the closure weld on the top plug weldment and the attachment weld on the drum bottom are examined, clean and locally passivate the weld areas and heat affected zone areas.

3.5 Dimensional Inspection Reports

Straightening, flattening, and forming by mechanical or thermal means of some features and components after welding may be required to ensure proper assembly. The surfaces of areas of the weldment that have been worked shall be visually examined to ensure that no cracks are present or that the weldment has been degraded. Adjacent welds to these areas shall also be visually examined. The acceptance criteria are that no cracks are found. The areas worked and the visual inspections shall be noted on the dimensional inspection report. This work and examination shall be performed prior to the installation of Kaolite or Catalog No. 277-4.

After all testing, inspection and final machining, the Drum Assemblies shall be dimensionally inspected. The dimensions, and features such as flatness, runout, etc, to be inspected are indicated on the Company's drawings. A written inspection report shall be prepared, and submitted to the Company as stated in the Procurement Specification for the ES-3100 Drum Assembly.

APPENDIX 1.4.3

EQUIPMENT SPECIFICATION JS-YMN3-801580-A001, *ES-3100 CONTAINMENT VESSEL*

EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO.	REV.	ISSUE DATE
JS-YMN3-801580-A001	E	10-15-03
PAGE: i OF ii	REVISION DATE: 03-15-06	
PROCURED BY: BWXT L.L.C.	INSTALLED BY: BWXT L.L.C.	

PROJECT TITLE	PLANT	BUILDING
ES-3100 Shipping Package	Y-12	AREA
JOB TITLE: Production Design Definition	W.O. OR E.S.O.: 7RCPCA5A	RECORD NUMBER: Y2003-0328
SPECIFICATION FOR: ES-3100 CONTAINMENT VESSELS		SSC IDENTIFICATION NUMBER:

ENGINEERING AND PLANT APPROVALS

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY: J.L. Heck	10-21-03	PROJECT ENGINEER: M.R. Feldman	10-29-03
DISCIPLINE MANAGER: J.C. Walls	10-29-03	OPERATIONS MANAGER/SYSTEM OWNER:	
DESIGN VERIFICATION: Roger Aigner	10-21-03		

REVISIONS/ENGINEERING AND PLANT APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issued Approved
B	Included the requirements for a Containment Vessel that was fabricated by welding a forged bottom, a forged top flange and a cylindrical shell as shown on the revised drawing, M2E801580A012, Rev B.
C	In all locations removed the references to the Procurement Specification document number OO-PP-1210. Modified the Weld Repair reject and re-qualification requirements in Section 3.3 in the fourth paragraph. In Section 3.9, first, third, and fourth paragraphs changed the units from ref-cm^3/sec to cm^3/sec helium. Also added new Section 3.6 Welding Documentation Submittals.
D	Added two paragraphs to the end of Section 3.1 for reference to ASTM A 262 in accordance with REDC #PE-05-046-A. Added a sentence to the beginning of the first paragraph in Sect. 3.9 in accordance with REDC # PE-06-059.
E	Section 3.0, paragraph 3, the phrase "the Company's written approval" has been revised to "the Company's written approval, and regulatory authority's written approval."

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY: G. A. Byington /s/	03/15/06	PROJECT ENGINEER: J. Arbital	03/15/06
DISCIPLINE MANAGER: C. M. Amonett /s/	03/15/06	OPERATIONS MANAGER/SYSTEM OWNER:	
DESIGN VERIFICATION: Roger D. Aigner /s/	03/15/06		

This document has been has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner /s/ Date: 03/15/06

EXEMPT FROM 10-155

TABLE OF CONTENTS **PAGE**

LIST OF COMPANY DRAWINGS

Drawing Number	Title
M2E-801580-A011	Containment Vessel Assembly
M2E-801580-A012	Containment Vessel Body Assembly
M2E-801580-A013	Containment Vessel O-ring Details
M2E-801580-A014	Containment Vessel Lid Assembly
M2E-801580-A015	Containment Vessel Sealing Lid
M2E-801580-A016	Containment Vessel Closure Nut
M2E-801580-A021	Containment Vessel Body Test Flange Assembly
M2E-801580-A022	Containment Vessel Lid Test Flange Assembly
M2E-801580-A023	Containment Vessel Leak Test Assemblies

EQUIPMENT SPECIFICATION

ES-3100 Containment Vessel

SPECIFICATION NO.	REV.
JS-YMN3-801580-A001	E
ISSUE DATE: 10-15-04	REVISION DATE: 03-15-06
PLANT: Y-12	PAGE: 1 OF 10

1.0 SCOPE

This specification, the Procurement Specification for the ES-3100 Containment Vessel, OO-PP-986, Procurement Specification For 70A Durometer Preformed Packing (O-rings), the Company's drawings, and the referenced codes and standards in section 2.0 of this specification state the requirements for the procurement of materials and components, fabrication, inspection, examination, assembly, and testing of the Containment Vessels for the ES-3100 shipping package. If conflicting requirements appear between the Company's drawings and specifications, the Seller shall immediately notify the Company, so that these can be resolved. The Seller shall provide the number of completed assemblies specified in the purchase order.

The Containment Vessel will be manufactured in accordance with the applicable requirements stated in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB for Class 1 Components as described on the Company's drawings and in this specification. If the Seller does not have certificate of authorization from the ASME to apply the N stamp, the Seller shall be familiar with, and capable of meeting those requirements in Section III, Division 1, Subsections NB and NCA of the ASME Boiler and Pressure Vessel Code that are referenced in this specification. The reference to the Inspector in any of the ASME Codes shall in this particular case be that person designated by the Company.

2.0 APPLICABLE CODES AND STANDARDS

The Containment Vessel shall be fabricated, inspected, and tested according to the design drawings and the following codes, standards, and regulations as described in this document.

- American National Standards Institute, ANSI N14.5-1997, American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Division 1 - Subsections NB and NCA, Class 1 Components, 2001 Edition and 2002 and 2003 addenda.

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Parts A and C, 2001 Edition and 2002 and 2003 addenda.

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section V, 2001 Edition and 2002 and 2003 addenda.

- American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section IX, 2001 Edition and 2002 and 2003 addenda.

- American Society For Nondestructive Testing, No. SNT-TC-1A-1992, Recommended Practice for Nondestructive Testing Personnel Qualification and Certification, Dec 1992.

- American Society For Testing Materials, ASTM A 380-99$^{\epsilon 1}$, Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems.

- Society for Protective Coatings, SSPC SP 5/NACE No. 1, White Metal Blast Cleaning

3.0 DETAILED REQUIREMENTS

Detailed dimensional requirements and the materials of construction are called out on the Company's drawings. Additional requirements for materials are given in section 3.1 of this specification. The Seller shall be responsible for determining stock sizes so that the finished machined components meet the dimensions, tolerances and surface features called out on the attached drawings.

Weld symbols are provided on the Company's drawings indicating the type of weld and dimensions for each weld. Additional welding and repair welding requirements are stated in sections 3.1 and 3.3 of this specification.

Any material substitution or other deviation from the requirements shown on the Company's drawings or stated in the Company's specifications is not permitted without the Seller submitting a written request for waiver or deviation, and Company's written approval, and regulatory authority's written approval (see the Procurement Specification for the ES-3100 Containment Vessel).

The term ASME Code in this specification refers to the ASME Boiler and Pressure Vessel Code. A paragraph referenced as NB-XXXX or NCA-XXXX, where XXXX is a specific paragraph number, is that paragraph in Section III, Subsection NB or Subsection NCA, respectively, of the ASME Code. If a given paragraph is referenced as a requirement, all the paragraphs under the stated paragraph are also to be considered as requirements. For example, if NB-2430 is referenced as a requirement, not only do the applicable requirements of NB-2430 apply, but also those of NB-2431, NB-2431.1, NB-2431.1(a), NB-2432, etc. apply. Note that the Company shall act as the Authorized Inspector, and that the Inspector referenced in the Code shall be a representative of the Company.

The assembled Containment Vessels shall be marked according to the Company's drawings. Permanent serial numbers for each Containment Vessel shall be assigned by the Company. Containment Vessel records may be maintained based upon a temporary serial number assigned by the Seller. The temporary serial number for the Containment Vessel shall be cross referenced to the Containment Vessel's permanent serial number.

The following additional requirements apply as follows:

3.1 Materials and Material Examinations

The containment vessel body (drawing M2E-801580-A012), the sealing lid, (drawing M2E-801580-A015), and the closure nut (drawing M2E-801580-A016), shall be considered pressure retaining materials as defined in paragraph NB-2110, and meet the applicable requirements of NB-2120. Documented Certified Material Test Reports (CMTR's) shall be provided to the Company for the materials used to fabricate these components in accordance with NCA-3860. The suppliers of these materials shall meet the requirements of NCA-3800. Such parts shall be traceable to each containment vessel by means of a serial number assigned by the Company. The Seller shall maintain control of materials to ensure this traceability. Other metallic materials, and the O-ring seals shall be supplied with Certificate of Compliances in accordance with NCA-3862(g) and (h).

Procured materials shall be examined in accordance with the applicable paragraphs of NB-2500, and shall meet the stated acceptance criteria. The results of these examinations shall be included with the CMTR's provided to the Company. Prior written approval of the Company shall be obtained for any weld repair on materials, and the weld repair areas shall be both surface and volumetrically examined. The repair area shall be noted in a sketch supplied with the CMTR for the material that was weld repaired and the documented results of the weld examination shall be provided to the Company. Note that depending on the specific defect in a specific material, the Company may or may not approve the weld repair, even if it is permitted by the material specification or by paragraph NB-2500.

The weld filler metal used in the fabrication and repair welding as permitted, of the Containment Vessels shall meet the applicable requirements of NB-2400. It shall be procured to comply with the SFA specifications of Section II, Part C of the ASME Code that is stated in the Seller's welding procedure specifications. Weld metal filler shall be procured traceable to heat numbers, and Certified Material Test Reports shall be furnished to the Company for each heat of weld wire filler used. The results of the delta ferrite determination shall be included in the CMTR for the weld filler metal (see NB-2433). The control of weld filler by the Seller shall permit a weld examiner to be able to determine the heat number of the weld filler used in any weld on the Containment Vessel.

The Seller shall provide the Company with certified material test reports, certified material examination reports and certificates of compliance for the materials stated above as required by the Procurement Specification for the ES-3100 Containment Vessel.

There are two containment vessel assemblies shown on drawing M2E801580A012, part number M2E801580A012-1, and M2E801580A012-4. The containment vessel assembly(s) to be fabricated will be specified in the Company's purchase order. Note that part M2E801580A012-4 is fabricated by welding a forged bottom, and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing.

The formed containment vessel body, part number M2E801580A012-1, shall be formed from a single forged billet or bar by any process that meets the requirements stated in this specification, and shown on the Company's drawings. Such processes may include forging, flow forming, metal spinning. Special requirements for this part are given as follows.

Repair welds may be permitted depending on the nature of the defect to be weld repaired, and after receiving the written approval of the Company for such repair welds.

The formed, heat treated, and finished machined containment vessel body part number M2E801580A012-1, shall meet the applicable requirements of ASME SA 182 for Grade F304L for a forged component. After final forming, parts shall be solution annealed and quenched per the requirements of ASME SA 182 for Grade F304L. In addition, the requirements of NB-2180 shall also apply. A certified heat treatment report shall be provided stating for each furnace charge the following information: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in process annealing and final heat treatment.

It shall be demonstrated that the formed, heat-treated containment vessel bodies part number M2E801580A012-1 meet the mechanical property requirements of ASME SA 182 for Grade F304L by mechanical testing of coupons. The test coupons are to be machined from the same heats of materials used to form the containment vessel bodies, and shall have the same or greater amount of cold word (plastic strain) as the containment vessels will have as a result of the forming process. The mechanical tensile testing of coupons shall be done in accordance with ASME SA 370. A minimum of six test coupons shall be tested for each final heat treatment furnace charge. The first set of three test coupons, chosen at random, shall be tested without being heat treated. The second set of three of more test coupons shall be heat treated together with the containment vessel bodies, and then tested. The heating rates and maximum temperatures of the test coupons shall be representative of the entire furnace charge. Test coupons are not required to be heat treated with intermediate processing annealing steps, but are required in the final heat treatment furnace charge.

The results of all the testing of the sample coupons shall be documented, certified and reported to the Company. The mechanical properties test report shall contain the following 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.

It is permissible to deviate from the liquid quench requirements stated in SA 182 provided that the cooling rates of the alternate quench are such that the heat treated material is not susceptible to intergranular corrosion due to chromium carbide precipitation. This is to be demonstrated by testing according to Practice E of ASTM A 262, and meeting the stated acceptance criteria. This shall be accomplished by obtaining test coupons from each furnace batch that represent the slowest cooling rates of the batch, or by following a heat treating procedure that has been qualified to ensure that the heat treated batch will not be sensitive to intergranular corrosion. In any case, the requirements of NB-2180 shall apply.

The heat treating procedure must be qualified by measuring the annealing temperatures, soak times and cooling rates of the furnace batch, and then testing heat treated specimens that represent the lowest annealing temperatures, soak times and cooling rates for that furnace batch for sensitivity to intergranular corrosion using Practice E of ASTM A 262. For subsequent annealing operations, the temperatures, soak times and cooling rates of subsequent furnace batches must be measured and compared to the qualified procedure. Other factors, such as variations of the size and arrangement of the furnace batch that can affect part temperatures and part cooling rates, and the calibration of the furnace temperature sensors must be assessed in the procedure qualification to ensure that minimum temperatures and cooling rates of production heat treating batches can be properly compared to those of the qualified procedure. Such a procedure should be requalified for each individual furnace used, and for significantly different furnace batch sizes. The procedure shall be requalified annually, or if it has not been used for a period of at least three months.

3.2 Forming, Fitting and Alignment

The forming, fitting and alignment requirements stated in paragraph NB-4200 shall be met in the fabrication of the Containment Vessels unless more stringent requirements are called out on the Company's drawings.

The roundness of cylinders, profile of formed head surfaces, and misalignment or offsets in weld joints shall be included in the dimensional inspection reports for the each Containment Vessel, see section 3.11 of this specification.

3.3 Welding and Weld Repair

All welds on the Containment Vessels shall be done either by the GTAW or GMAW process, manual or automatic, at the discretion of the Seller unless specifically called out on the drawings. Backing rings, even if removed after the weld has been made, shall not be used. As previously stated, weld symbols are provided on the drawing indicating for each weld the type of weld and dimensions of the weld.

Except as limited by this specification, the applicable requirements of NB-4300 and NB-4400 shall apply to the Containment Vessel.

Prior to welding, all weld preparation areas and the surfaces within one inch of the weld area shall be examined visually and with liquid penetrant. The acceptance criteria for these examinations are those stated in NB-5130 (a) through NB-5130 (d). The results of these surface examinations shall be reported to the Company together with the weld examination reports, see section 3.4 of this specification.

Welders performing two or more welds in one day that are rejected based upon welder technique shall be subject to be re-qualified to the appropriate welding procedures, see Section IX, paragraph QW-320 of the ASME Code.

3.4 Weld Examination

The applicable requirements in paragraphs NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, and NB-5300 shall apply to the Containment Vessels. The plug weld shown on drawing M2E801580A015 shall be examined visually and with penetrant. The applicable requirements in paragraphs NB-5110, and NB-5350 shall apply to the plug weld. Note that the reference to the Inspector in NB-5112, for the purposes of this specification is either the Company's inspector or a subcontractor designated by the Company.

Materials used in the penetrant examination of welds and in the final surface examination of finished components (see section 3.7) shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used (see Section V, Article 6, T-641) shall be supplied to the Company with the examination reports.

Repair welding shall meet the applicable requirements of NB-2500.

Certified written weld examination reports together with the corresponding material surface examination reports, and weld map shall be submitted to the Company as stated in the Procurement Specification for the ES-3100 Containment Vessel. Weld examination reports for all weld and surface examination shall include: the Containment Vessel serial number, a weld map showing the location of the weld and examination area, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure(s) number used, the WPS number, the heat numbers of the materials joined, the heat number of the weld filler, and examiner's remarks. The examiner's remarks shall include the results of the examination and acceptance, or rejection of the weld based on the stated criteria. One set of radiographs shall be provided to the Company with radiographic examination reports. If the weld or surface is rejected, a description of the defect and sketch showing the location shall be provided.

If a weld is rejected, the area shall be weld repaired by the Seller and re-examined. After two unsuccessful repair attempts, the Company shall be notified for approval to perform more repair attempts. The Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

3.5 NDE Examiner Qualifications

The qualifications of the personnel performing material or weld examination shall be those stated in paragraph NB-5500.

3.6 Welding Documentation Submittals

A. Submittal of the following are required with the bid unless the current revisions of these submittals have been previously approved by the Company. Submittals that do not demonstrate compliance with this specification will be cause for rejection of the proposal.
   1. Typical welding procedure specifications (WPS) for the applicable code.
   2. Procedure qualification records (PQR).
   3. Typical welder performance qualification (WPQ) records for the appropriate code.

B. Submittal of the following documents are required prior to welding unless the current revisions of these submittals have been previously approved by the Company.
   1. Welding Procedure Specifications (WPS).
   2. Procedure Qualification Records (PQR).
   3. Welder Performance Qualification (WPQ) records, including evidence of process usage updates.
   4. Visual examination and nondestructive examination procedures.
   5. Certification records of examination personnel.
   6. Certified Material Test Reports.

C. To facilitate prompt review by the Company of the Seller's weld program, the welding documentation required above shall be submitted electronically in Adobe pdf format either on compact disk (CD) or by email. All information submitted shall reflect the Seller's most current documentation. Upon review and approval of the documentation, the Seller will be notified.

D. If the latest revision of the Seller's welding documentation required above has been previously submitted electronically and reviewed and approved by the Company, this shall be so stated with the offer. The Seller shall submit a detailed list of the welding documentation to be used for this contract including title, revisions/dates, type components to be used on (i.e., piping, structural, sheet metal, etc.) and indicate the previous contract and approval date. The Company will then review the documentation for applicability on the new contract and approve or comment.

E. If changes have occurred since the last approval of the welding documentation, in addition to the list of welding documentation that they propose to use the Seller shall submit those documents that have changed. The Company will then review, comment and/or approve the Seller's documentation.

3.7 Hydrostatic Testing

After all machining is complete, the assembled Containment Vessel shall be hydrostatic tested by the Seller in accordance with the applicable sections of NB-6000 at a test pressure of 150 psig +/- 5 psig at ambient temperature (60°F to 90°F). Water with a maximum chlorine content of 0.5 parts per million shall be used as a test medium.

It will be necessary to hydrostatically test the Container Body Assembly separately from the Lid Assembly. It is recommended that the tooling shown on the Company's drawings M2E801580A021, M2E801580A022, and M2E801580A023 be used to pressurize the components to be tested. The use of this tooling is not mandatory, but the Seller shall provide suitable fittings to perform the hydrostatic testing.

A written hydrostatic test procedure shall be prepared by the Seller and submitted to the Company for approval prior to testing. Certified written hydrostatic test reports for each Containment Vessel shall contain the following data: serial number of the Containment Vessel; time and date of the test; name of person responsible for the hydrostatic testing; the hydrostatic test procedure number; the name, serial number and calibration date of all gages and transducers; and a sketch showing any areas of leakage or any areas where surface defects were observed after hydrostatic testing. Hydrostatic test reports shall be submitted to the Company as stated in the Procurement Specification for the ES-3100 Containment Vessel.

3.8 Final Examination of Finished Surfaces

After all finish machining, load testing and hydrostatic testing, all surfaces of the containment vessel body, drawing M2E801580A012; the containment vessel sealing lid, drawing M2E801580A015; and the containment vessel closure nut, drawing M2E801580A016, shall be examined with penetrant in accordance with NB-2546. See section 3.4 for additional requirements for the materials used in the penetrant examination. The results of the final surface examinations shall be documented in a certified examination report and provided to the Company as stated in the Procurement Specification for the ES-3100 Containment Vessel.

If a defect is found, the Company shall be notified in writing. The area may be weld repaired by the Seller only if specifically permitted by the Company in writing, and the area re-examined. After two unsuccessful repair attempts, the Company may, at its option, choose to reject further repair efforts and require that a replacement part be fabricated.

3.9 Leak Testing

There are three leak tests to be performed on the ES-3100 Containment Vessel. The leak testing is to be performed after Hydrostatic Testing. Following the hydrostatic pressure test and prior to conducting any leak test, the containment vessel and O-ring cavities must be thoroughly dried. The leak testing is to be performed in accordance with the applicable sections of ANSI N14.5-1-1997. A written leak test procedure(s) shall be prepared to perform this testing and submitted to the Company for approval, see the Procurement Specification for the ES-3100 Containment Vessel. The written test procedure(s) and leak testing report shall comply with the applicable requirements of Section V of the ASME Boiler and Pressure Vessel Code. The leak testing for the first two leak tests shall have the sensitivity to detect a leak less than or equal to 5×10^{-8} ref-cm^3/sec of air, or 9×10^{-8} cm^3/sec helium and shall use the leak test fixtures shown on the Company's drawings M2E801580A021, M2E801580A022, and M2E801580A023.

If a leak is found the Company shall be notified in writing. The leak may be weld repaired by the Seller only if specifically permitted by the Company in writing, and the leak test repeated. After two unsuccessful repair attempts, the Company may, at its option, choose to reject further repair efforts, and require that a replacement part be fabricated.

The first leak test shall be performed with the containment vessel body assembled as shown on drawing M2E801580A023-1. Note that the outer O-ring in the containment vessel body is not to be installed for this test. The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than 1×10^{-7} ref-cm^3/sec of air, or 1.9×10^{-7} cm^3/sec helium.

The second leak test shall be performed with the containment vessel lid assembly as shown on drawing M2E801580A023-2. The leak testing acceptance criteria is that the assembly shall not have an integrated leak rate greater than 1×10^{-7} ref-cm^3/sec of air, or 1.9×10^{-7} cm^3/sec helium.

The third leak test is to be performed with the Containment Vessel assembled as shown on drawing M2E801580A011. The sensitivity of the leak testing procedure for the third leak test shall be capable of detecting a leak rate of 1×10^{-4} ref-cm^3/sec of air, and that the acceptance criteria shall be that no leaks are detected. The third leak test shall verify that there is no detectable leakage between the two O-rings that seal the lid to the body at the detectable rate specified.

Certified written leak test reports shall be supplied to the Company that describes the leak testing and results. The test report shall identify the Containment Vessel serial number, identify all standard leaks, gauges, transducers and electronic readouts, give the date on which these instruments were certified, identify the leak detector, give the date on which the leak detector was last certified, the date of the test, time of the start and end of the test, the recorded pressures and leak rates at the start and end of the test, the name of the person conducting the test, the qualifications of the person conducting the test, identify areas of the Containment Vessel where repairs were made and any pertinent remarks. Leak testing reports shall be submitted to the Company as stated in the Procurement Specification for the ES-3100 Containment Vessel.

3.10 Cleaning, Passivation, and Bead Blasting

Cleaning procedures for the stainless steel, including weld areas, shall be submitted to the Company for approval prior to the start of fabrication. Only non-chloride bearing chemicals shall be used for cleaning (such as trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 0.5 parts per million.

Finished components awaiting assembly and assemblies shall be free of dirt, debris, foreign objects, cutting fluids, metal chips, grinding residue, dye penetrant and developer, and other foreign substances. The Seller shall clean, cover, and protect parts and subassemblies from becoming dirty while in storage, and to the extent practical, in the shop environment while in work.

After final machining, and all examination of welds and surfaces, clean and passivate all stainless steel surfaces of the containment vessel in accordance with ASTM A 380. After passivating is complete, bead blast all exterior surfaces in accordance with SSPC-SP 5/NACE No. 1, White Metal Blast Cleaning with the exception of all sealing surfaces and threaded surfaces.

3.11 Dimensional Inspection Reports

After all testing, inspection and final machining, the Containment Vessels shall be dimensionally inspected. The dimensions and features to be inspected are indicated on the Company's drawings by a diamond symbol containing an "I". This dimensional inspection includes surface features such as flatness, runout, etc, as called out on the drawings. The dimensional inspection report shall also include the recorded diameter dimensions that show compliance with the requirements of paragraph NB-4200. A certified written inspection report shall prepared and submitted to the Company as stated in the Procurement Specification for the ES-3100 Containment Vessel.

APPENDIX 1.4.4

EQUIPMENT SPECIFICATION, JS-YMN3-801580-A003, *MANUFACTURING PROCESS SPECIFICATION FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE*

EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO.	REV	ISSUE DATE
JS-YMN3-801580-A003	C	11/24/03
PAGE: i OF ii	REVISION DATE:	6/1/06
PROCURED BY: BWXT L.L.C.	INSTALLED BY:	BWXT L.L.C.

PROJECT TITLE	PLANT	BUILDING
ES-3100 SHIPPING PACKAGE	Y-12	YAREA-00
JOB TITLE	**W.O. OR E.S.O.**	**RECORD NUMBER**
Production Design Definition	7RCPCA08	2003-0328

SPECIFICATION FOR: MANUFACTURING PROCESS SPECIFICATON FOR CASTING KAOLITE 1600™ INTO THE ES-3100 SHIPPING PACKAGE

SSC IDENTIFICATION NUMBER:

ENGINEERING AND PLANT APPROVALS

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY: R. D. Aigner	11-25-03	PROJECT ENGINEER: G. A. Byington	11-25-03
DISCIPLINE MANAGER: J. C. Walls	11-25-03	OPERATIONS MANAGER/SYSTEM OWNER:	
DESIGN VERIFICATION: R. D. Aigner	11-25-03		

REVISIONS/ENGINEERING AND PLANT APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issue for procurement
B	Removed the reference to the Prototype Procurement Specification document number OO-PP-1210. Change the equipment reference in Section 3.1.3(c) from a "large mortar mixer or plaster mixer with moving vanes or a smooth wall cement mixer with the fixed vanes removed" to "Whiteman Multiquip's WM700S-H8 plaster/mortar mixer, refereed to as WM700". In Section 3.2 changed the method and time that the water and dry mix were added into the mixer based upon the mixer qualification in Section 3.5. Added Section 3.5, added attachments E and F to determine the proper mixing time and the Mixer Qualification Castings. In section 3.3.1 and 3.3.3 added misting procedure. Section 3.3.2(b) added a circular concave of .32±.10 to the Kaolite before it is baked to match drawing M2E801580A002. Section 3.3.4(b) add a circular convex scrape of .09±.06 to the Kaolite before it is baked to match drawing M2E801580A008. Updated the attachments with general revisions. Section 3.4 has been subdivided into 3.4.1 Baking Instruction and 3.4.2 Baking Documentation and added attachment F to this section.
C	Revised patent information in scope. Added recommended "Before Baking" weights for the Body Weldment and Top Plug Weldment based upon a more refined Kaolite 1600™ product code GI80ACCUMD0027 that is produced to the lower side and a smaller range of the manufactures normal tolerance band. This Kaolite 1600™ product code requires using 1.65 times the dry weight for the water weight (instead of 1.5) and generates an acceptable wet mix density of 56.2+/- 5.8 lb/ft^3. This additional water requires between 36 to 46 hours of bake time at 500°F.

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY: [signature]	6/1/06	PROJECT MANAGER: [signature]	6/1/06
DISCIPLINE MANAGER: C.M. Amonett for W.I. North	6/1/06	CRITICALITY SAFETY: [signature]	6/1/06
DESIGN VERIFICATION: Monty L Goins	6/1/06	QUALITY ASSURANCE: [signature]	6/1/06

This document has been has been reviewed by a Y-12 ADC and UNCI RO and has been determined to be UNCLASSIFIED and not UNCI. This review does not constitute clearance for public release.

Name: [signature] Date: 06/01/06

EXEMPT FROM IO-155

TABLE OF CONTENTS

ATTACHMENTS

1 Scope

This manufacturing process specification describes the quality assurance and technical requirements that shall be met when weighing, mixing, pouring, vibrating, curing, and baking the Kaolite 1600™ for the ES-3100 shipping container Body Weldment and Top Plug Assemblies. The product produced by following this manufacturing process is protected under U.S. Patent 6,299,950. The United States Government has rights in this invention pursuant to Contract No. DE-AC05-84OR21400, between the U.S. Department of Energy and BWXT Y-12 L.L.C.

This specification describes the instructions that shall be followed for these activities. The components (Body Weldment and Top Plug Assembly) will be fabricated to the design requirements specified on the engineering drawings for the components.

Reference to the Company in this specification shall mean the package certificate holder and reference to the Seller shall mean the supplier of the fabricated Body Weldment and Top Plug Assemblies.

2 Applicable Documents

The following documents apply when Casting Kaolite 1600™ Into ES-3100 Shipping Containers.

ES-3100 Drawing Numbers
M2E801580A002, Body Weldment
M2E801580A008, Top Plug Weldment,

Procurement Specification for ES-3100 Confinement Boundary Assembly
JS-YMN3-801580-A002 Equipment Specification for the ES-3100 Drum Assembly

3 Kaolite 1600™ Processing Requirements

3.1 General

The Kaolite 1600™ material referenced with in this specification shall be provided by Thermal Ceramics, Incorporated or an authorized distributor. The material certification documentation (Certificate of Conformance) for the Kaolite 1600™ must be provided by the supplier for each manufacturer's lot of material to a product code of GI80ACCUMD0027.

3.1.1 Kaolite 1600™ Receiving and Storage Instructions

a. Damaged packages of Kaolite 1600™ shall be rejected by the Seller upon receipt. Damaged packages are those that are wet, those that are visually determined to have been wet, and packages that have been torn.

b. Packages of Kaolite 1600™ must be stored unopened in a dry location and protected from damage. Opened unused and partial used Kaolite 1600™ packages are to be discarded at the end of the work shift. The term work shift shall be defined by the Seller and approved by the Company before commencing operations.

3.1.2 Cleaning Instructions

a. Use NO CHLORINE BLEACH for cleaning. Potable water shall be used and if required some mild soap (tri-sodium phosphate) may be added to the water to clean all processing equipment and manufactured components before casting. Before the start of any mixing/blending operation, the mixer shall be clean from all foreign materials or previous mixing residues from the inner surface of the mixer. The mixer shall be flushed thoroughly with potable water at the completion of the final mixing operation of the work shift to remove residues. Mixing, and casting shall be performed within a temperature range of 70 (± 25) °F.

b. Fabricated assemblies must be cleaned and protected prior to the casting operation to prevent the introduction of foreign materials into the assemblies. The assemblies shall be inspected and wiped clean prior to casting to ensure no visible contaminants are present inside the casting cavity. This inspection shall be documented in the checklist.

3.1.3 Mixing Water and Mixing Equipment Requirements

a. Potable water, that has been filtered through a 20-micron filter and has a chlorine content less than 4 mg/L (4 ppm, 0.0004 percent by mass) for chlorine shall be used for the mixing of Kaolite 1600™. If the potable water is higher then 4 ppm, then use an activated charcoal filter or some other means to reduce the amount of chlorine to at or below 4 ppm. Test the water quality for chlorine weekly during casting operations. Unfiltered potable water may be used for the cleaning of equipment used to process Kaolite 1600™.

b. All weighing operations of assemblies and materials shall be conducted on certified scales with a minimum accuracy of ½ lb.

c. This specification has been developed around the Whiteman Multiquip's WM700S-H8 plaster/mortar mixer, refereed to as WM700. This steel-drum machine mixes 7-cubic feet (193 liters) of material with an 8-horsepower Honda engine running at a slow speed. Other models of plaster/mortar mixers may be used if the speeds and mix times are qualified per section 3.5 and approved by the company.

d. A Heavy Duty Drum Vibrator/Packer(like McMaster-Carr, No. 5809K11, or Company approved equal) shall be used to clamp the Body Weldment, M2E-801580-A002 or Top Plug Weldment, M2E-801580-A008 upside down for vibration casting the Kaolite 1600™ into the welded stainless steel forms.

3.2 Mixing of Kaolite 1600™

Mixing shall be performed by operators qualified in accordance with requirements in Section 4.4.

The term batch is defined as a mixture of one bag of Kaolite 1600™ with the appropriate amount of water. The required mix ratio is 1.65 pounds of filtered water per pound of Kaolite 1600™.

The mixing activity shall be recorded on Attachment A, *Kaolite Mixing Control*. Each batch shall be given a mixture control number (MCN) and recorded upon its data Attachment. (A 10-digit control number is recommended consisting of the date and the time format using a 24-hour clock. Example: 1021041515 for October 21, 2004 at 3:15 pm.)

The Kaolite 1600™ mixing shall be performed as follows:

a. Record the weight of the bag of Kaolite 1600™ on the mixing Attachment.

b. The required mix ratio is 1.65 pounds of filtered water per pound of Kaolite 1600™. For a 50 pound bag of Kaolite 1600™, weigh and record 82.5 (± ½) lbs. of filtered water generating an acceptable wet mix density of 56.2±5.8 lb/ft^3.

c. Start the mortar mixer motor and when ready to engage the moving vanes, pour the weighed filtered water, pour all of the 50-pound bag of Kaolite 1600™ over the water. Immediately start the WM700 moving vanes for 3.0 (±0.2) minutes.

3.3 Vibration Casting and Curing of Kaolite 1600™ into Assemblies

3.3.1 Body Weldment Casting Instructions

Casting operations shall be performed by operators and witnesses qualified in accordance with requirements listed in Section 4.4.

Use Attachment B, *Body Weldment Vibration Casting Control*, to record information gathered during this operation.

Complete the casting of the mixture in less than 70 minutes. This timed procedure starts when the first batch is poured into the vibrating component. The casting and vibrating procedure must be completed within 77 minutes from initial pour for each assembly.

Casting operations shall be performed as follows:

a. Weigh the Body Weldment clean and empty. Record the weight.

b. Fill the Body Weldment with potable water that has been filtered through a 20 micron filter and has a chlorine content of ≤ 4 ppm and weigh it. Record the weight.

c. Remove the water from the assembly as much as is practical.

d. Secure the assembly on the vibration table. Set the vibration table dial indicators to approximately 800 lb-force at 450 vibrations per minute (VPM). Assure that the Body Weldment is properly secured to the table and start the vibration table. The Body Weldment must be vibrated continuously throughout the casting operation.

e. The mixture shall then be poured directly into the assembly after mixing through the fill hole provided.

f. Repeat the mixing operation in Section 3.2 and continue pouring until the mixture overflows the fill hole by ½ to ¾ inch.

g. Mist the top surface of the mixture with a bottle water sprayer if necessary to get the mixture into a solution after the pouring is completed. Do not add more than 8 ounces of water.

h. Vibrate the filled assembly for 5 to 7 minutes after the casting is completed.

3.3.2 Body Weldment Curing Instructions

A designated area shall be set aside for curing the assemblies. The temperature of the curing area shall be controlled to 70°F (±25°F) and shall prevent the introduction of foreign materials into the mixture.

Curing operations shall be performed as follows:

a. Remove the Body Weldment from the vibration table and place it in the curing area. Let it rest uncovered for 2½ (±½) hours.

b. Weigh and record the Before Baking weight of the cast assembly. If the weight is outside of 330 to 386 lbs range it is recommended not to cure the casting but to clean out and recast the Kaolite. This Before Baking weight is a recommended process control for the finished baked density. The manufacture may continue with a part outside of this weight range but it has a high chance being rejected for not meeting the finished baked density.

c. After resting, scrape the excess mixture from the fill opening until the Kaolite surface has a circular concave of .32±.10 to match drawing M2E801580A002.

d. Weigh the cast assembly, and photograph the fill opening. Record the weight.

e. Cover the fill opening with plastic sheeting and let the assembly set undisturbed in the curing area for at least 24 hours.

3.3.3 Top Plug Assembly Casting Instructions

Use Attachment C, Top Plug Assembly Vibration Casting Control, to record information gathered during this operation.

Complete the casting of the mixture in less than 70 minutes. This timed procedure starts when the first batch is poured into the vibrating component. The casting and vibrating procedure must be completed within 77 minutes from initial pour for each assembly.

Casting operations shall be performed as follows:

a. Weigh the top plug assembly clean and empty. Record the weight.

b. Fill the top plug assembly with potable water that has been filtered through a 20-micron filter and has a chlorine content of ≤ 4 ppm and weigh it. Record the weight.

c. Remove the water from the assembly as much as practical.

d. Place the assembly on the vibration table. Assure that the assembly is properly secured to the table. Set the vibration table dial indicator to approximately 120 lb-force at 450 vibrations per minute and start the vibration table. The top plug assembly must be vibrated continuously throughout the casting operation.

e. The mixture shall then be poured directly into the assembly after mixing through the fill hole provided.

f. Repeat the mixing operation in Section 3.2 and continue pouring until the mixture overflows the fill hole by ½ to ¾ inch.

g. Mist the top surface of the mixture with a bottle water sprayer if necessary to get the mixture into a solution after the pouring is completed. Do not add more than 4 ounces of water.

h. Vibrate the filled assembly for 5 to 10 minutes after the casting is completed.

3.3.4 Top Plug Assembly Curing Instructions

Curing operations shall be performed as follows:

a. Remove the top plug assembly from the vibration table and place it in the curing area. Let it rest uncovered for 2½ (±½) hours.

b. Weigh and record the Before Baking weight of the cast assembly. If the weight is outside of 29.2 to 34.2 lbs range it is recommended not to cure the casting but to clean out and recast the Kaolite. This Before Baking weight is a recommended process control for the finished baked density. The manufacture may continue with a part outside of this weight range but it has a high chance being rejected for not meeting the finished baked density.

c. After resting, scrape the excess Kaolite mixture from the fill opening until surfaces are a circular convex shape of .09±.06 before it is baked to match drawing M2E801580A008.

d. Weigh the cast assembly, and photograph the fill opening. Record the weight.

e. Cover the fill opening with plastic sheeting and let the assembly set undisturbed in the curing area for at least 24 hours.

3.4 Baking of Assemblies Cast and Cured with Kaolite 1600™ mixture

3.4.1 Baking Instructions

Several assemblies may be baked together during each furnace heating cycle. Once the furnace heating cycle has started, no additional assemblies may be inserted into the furnace. The furnace and temperature control requirements to perform the baking operation are as follows:

a. The furnace shall be a gas-fired or a forced convection fresh air circulating electric furnace.

b. The furnace heat zone shall be certified to ±25°F from the furnace set point temperature at each baking temperature process point.

c. Furnace time and temperature strip charts for each furnace heating cycle shall be provided with each completed Attachment D. Alternatively, an ASCII furnace time and temperature data file may be provided for each completed Attachment D.

3.4.2 Baking Documentation

Use Attachment D, *Furnace and Baking Control*, to record information gathered during this operation. An Attachment D identified by the Baking Control Number (BCN) shall be generated for each set of assemblies subjected to the furnace baking operations. Record the BCN from Attachment D for each assembly baked during this furnace heating cycle utilizing the proper assembly Casting Attachments B, C, and F. Qualified operators as indicated in Section 4.4 shall perform the baking of the cured assemblies. Movement of the cured assemblies before baking shall be minimized. The time and actual furnace exhaust air temperature shall be recorded at least every 15 minutes for baking control during a furnace heating cycle.

The baking furnace heating cycle shall be completed as follows:

a. Place the assemblies into the furnace.

b. Set the initial set point temperature to 200 (±10) °F.

c. Hold the temperature for 4 hours at a 200 (±10) °F steady state.

d. Increase the furnace set point temperature to 275 (±10) °F.

e. Hold the temperature for 1 hour at a 275 (±10) °F steady state.

f. Increase the furnace set point temperature to 350 (±10) °F.

g. Hold the temperature for 1 hour at a 350 (±10) °F steady state.

h. Increase the furnace set point temperature to 425 (±10) °F.

i. Hold the temperature for 1 hour at a 425 (±10) °F steady state.

j. Increase the furnace set point temperature to 500 (±10) °F.

k. Hold the temperature for 41 (±5) hours at a 500 (±10) °F steady state.

l. Remove assemblies and allow cooling in still air until they reach ambient temperature.

m. Weigh the assemblies after the baking process and record the weights upon the appropriate Attachment (Attachment B or C). Calculate the baked density of the cured mixture using the equation at the bottom of Attachment B or C and record.

Acceptance criteria:

An acceptable baking process is defined as the process in which the density of the baked mixture in an assembly is within the acceptance range of 22.4 ±3 lb/ft^3 as defined on Attachments B or C. If the density is less than the allowable value, contact the Company for disposition. If the density is greater than the allowable level, then re-bake the assembly using Section 3.4.5.a through k, with the exception of the final hold time which shall be 5 (±0.5) hours. Remove assemblies and allow cooling in still air until they reach ambient temperature. Recalculate and record the density on the appropriate Attachment. If the density still is greater than the allowable level, contact the Company for disposition.

n. Photograph the surface of the baked mixture (digital images are preferred).

o. Following the acceptable baking process, weld the cover plate onto the assemblies in accordance with the appropriate engineering drawing within 24 hours.

p. Weigh the final assembly and record on the appropriate Attachment (Attachment B or C).

3.5 Mixer Qualification for Kaolite 1600™ Casting Placement

The mixer qualification process shall verify that the mixer speed and mix time are properly set to mix the Kaolite 1600™. The end result of the mixer qualification is the as-baked density of 22.4±1 lb/ft^3 in the Baked Mixer Qualification Samples. This baked density can be estimated by monitoring the wet density. The baked density is approximately 41% of the wet density; therefore, the Target Wet Density is 56.2 lb/ft^3 for an average baked density of 22.4±1 lb/ft^3. The longer the Kaolite 1600™ is mixed the denser it becomes. The mixer qualification process shall verify the mix time required at a fixed and repeatable speed. The operators shall use the mixer to determine a repeatable speed to operate the mixer for all of the tests. Record the speed setting and assure that the speed setting is repeatable. The mixer qualification tests are a two step process: first is a Wet Density Mixer Time Vibration Casting test used to determine the range of mix time versus wet density; second is the mixer Baked Density Qualification Sample Vibration Casting. It is recommended that a 4-gallon or larger metal pail be used for the testing like the 4-1/2 gallon Tin-Plated Steel Pail (McMaster-Carr 4243T16 or equivalent), 9" Top Dia, 19-3/8" Height.

3.5.1 Wet Density Mixing Test

Use Attachment E, *Wet Density Mixer Time Vibration Casting*, to record information gathered during this operation.

Prepare the Kaolite 1600™ and water for mixing per section 3.2 except for the mix time. A digital stop watch shall be used to monitor the running mix time. The mix time shall vary per Form F from 1 to 15 minutes in 1 minute intervals. Use a quick release attachment to affix the two metal pails (at least 4 gallon) to the vibration table. Start the mixer and run it for one minute, start the vibration table and pour the Kaolite 1600™ into the two pails after filling let them vibrate for 2 minutes, stop the vibration table, scrape them flush, and remove the pails and weigh them. Record the weight, dump the Kaolite 1600™ back into the mixer and start the mixer for another minute and repeat the process.

Plot the wet mix density of the two pails versus the mix time in an Excel file. An Excel file generated by the Company can be provided for this task upon request. Curve fit the data using a third order polynomial curve and show the equation. Plot the target density of 56.2 lb/ft^3 on a chart in Excel along with the wet mix density. Where the curves intersect the target density line is the mixer's target mix time. Consult the Company for verification of this data. Use the Company verified mix time for the Mixer Baked Density Qualification Castings in Section 3.5.2.

3.5.2 Mixer Baked Density Qualification Castings

Use Attachment F, *Baked Qualification Density Sample Vibration Casting*, to record information gathered during this operation.

Prepare the Kaolite 1600™ and water for mixing per section 3.2.1 except for the mix time. A digital stop watch shall be used to obtain the Company verified mix time. Start mixer and run it for the Company verified mix time. Start the vibration table and pour the Kaolite 1600™ into the two pails. After filling, let them vibrate for 5 to 7 minutes then stop the vibration table.

Remove the two pails from the vibration table. Place the filled two pails in the curing area, and let them sit uncovered for 2½ (±½) hours. After sitting 2½ (±½) hours, scrape the excess mixture from the fill opening until surfaces are flush. Cover the fill opening with plastic sheeting or a metal lid and let the assembly sit undisturbed in the curing area for at least 24 hours before weighing. Remove the two pails and weigh the cured qualification samples to an accuracy ±1 pounds. Record the as-cured and after-baking weights and follow the baking instructions in section 3.4.

4. Quality Assurance Requirements

4.1 General

4.1.1 The Seller shall have a quality assurance program that meets the applicable requirements of Title 10 CFR Part 71, Subpart H for packaging and transportation of radioactive material. The quality assurance plan shall be in accordance with the requirements identified in the ES-3100 procurement specification. The Seller shall submit an approved quality assurance program plan that describes the quality assurance policies and practices to be implemented in identifying, controlling and verifying quality of the Kaolite 1600™ processes (weighing, mixing, pouring, vibrating, curing, and baking).

4.1.2 The Seller shall submit a Manufacturing Plan as defined in procurement specification, and shall describe how the Seller will comply with the instructions in this specification. If subcontractors are utilized for any of the processing of the Kaolite 1600™, the Seller shall ensure that the requirements of this specification (including quality assurance requirements) are met by all suppliers and subcontractors. The subcontractor's procedures, approved by the Seller, shall be included in the procedures submitted to the Company for review and approval.

4.1.3 The Seller's quality assurance program plan shall include the requirements for the process controls for the operations, operator and witness' qualifications, and verification records. Operator qualification requirements are identified in Section 4.4.

4.1.4 The Seller shall generate the documentation necessary to show compliance with the approved quality assurance program plan. All records shall be identified based on the assembly serial numbers. The Seller shall maintain quality-related documentation in accordance with requirements in the procurement specification. The Company reserves the right to request any such documentation and to witness all aspects of the fabrication process in accordance with this specification. The Seller shall ensure that the specified manufacturing and inspection records are generated and supplied to the Company as part of the certification package.

4.1.5 The Seller must ensure all operators are aware of and comply with the quality assurance requirements identified in this specification. The Seller must ensure all operators use and follow written procedures for the respective processes. The Seller shall ensure operators and witnesses are aware of the operational requirements for the common industrial equipment (material handling equipment, mixers, vibration tables, ovens/furnace) used for the processes.

4.2 Material and Equipment Certification

4.2.1 Material certification for the Kaolite 1600™ must be provided by the supplier as defined in Section 8.0 of the procurement specification. Bags of Kaolite 1600™ must be identified with the product name and unique lot number. The material certification will be incorporated into the quality assurance records of the certification package.

4.2.3 All weighting, mixing, casting, curing, and baking processes shall be controlled and performed by qualified personnel (see Section 4.4). Written procedures shall be utilized by the operator at each operation and shall identify process hold points where required by the Company.

4.2.4 All process equipment used for mixing, casting, and baking of the Kaolite 1600™ and water mixture must be the model type identified in this specification, and must be in good working condition. Equipment used for measurements must be certified to traceable NIST standards or similar agency. Variation from specified equipment (vibration table, mixer, and furnace) is not allowed without the written approval of the Company before implementation.

4.3 Nonconformance Control

4.3.1 The Seller shall have an approved procedure for the control of nonconformances, waivers, and deviation requests during the execution of this manufacturing specification.

4.3.2 Nonconforming components shall not be used unless it has been determined by analysis or assessment by the Company that the nonconformance does not impact the physical properties of the material.

4.2.3 The disposition of nonconforming components shall be documented. Any nonconforming component shall be clearly identified and all nonconformance reports shall be traceable to the actual component affected. Copies of all approved nonconformance reports, except for scrapped components shall be supplied by the Seller to the Company as part of the certification package.

4.4 Operator and Witness Qualifications

The Kaolite™ 1600 mixing and vibration casting qualification evaluations shall be sequential. Each operator must mix and cast at least one simulated drum. Mixing and casting operations shall be repeated as necessary to achieve fully cast mock drums. The simulated ES-3100 drums cast during qualification activities shall be baked according to procedure.

4.4.1 Kaolite 1600™ Mixing Process Qualifications

Each operator and witness performing Kaolite 1600™ mixing activities must be qualified to perform this activity. This qualification shall be documented. This qualification shall consist of the following:

a. Location and time.

b. Properly identifying a bag of Kaolite 1600™ the bag of material and associated certification data (such as lot numbers)

c. Inspection of the bag for observable damage (such as water damage)

d. Successfully weighing the bag of Kaolite 1600™ on an industrial scale

e. Successfully calculating the required amount of water to be mixed with the Kaolite 1600™ (1.65 pounds of water per pound of Kaolite 1600™)

f. Properly inspecting the mixing equipment for foreign materials (such as oil, grease, free liquids, trash, or evidence of non-Kaolite 1600™ material affixed to the inner surfaces.)

g. Successfully operating the mixing equipment while mixing a complete bag of Kaolite 1600™.

h. Successfully preparing a uniformly mixed batch of Kaolite 1600™. (Uniformly shall be defined as a thoroughly mixed material with no dry material and no free liquids remaining in the mixer.)

4.4.2 Kaolite 1600™ Vibration Casting Process Qualifications

Each operator and witness performing Kaolite 1600™ casting activities must be qualified by successfully performing a casting activity. This qualification shall consist of the following.

a. Properly inspecting the inner surfaces of an empty simulated ES-3100 drum body for residues (oil, grease, free liquids) and waste material. (A simulated ES-3100 drum body shall consist of a 55-gallon carbon steel open-head drum which has a 16-gallon carbon steel drum secured to the bottom center. The 16-gallon drum may be secured by tack welding or suitable fasteners. The lid of the 55-gallon drum must have an opening 15" in diameter through which the Kaolite 1600™ can be poured into the drum.)

b. Properly securing an empty simulated ES-3100 drum body to the vibration table.

c. Properly adjusting the vibration table controls to the specified values for drum assemblies.

d. Successfully transferring the Kaolite 1600™ from the mixer into the drum while the drum is vibrating.

4.4.3 Kaolite 1600™ Baking Process Qualifications

Each operator and witness performing Kaolite 1600™ baking operations shall review the procedure steps for calculating the as-baked density of the Kaolite 1600™ in the assemblies and perform a sample calculation.

Attachment A EQUIPMENT SPECIFICATION ES-3100 Shipping Package Kaolite Mixing Control	Specification Number JS-YMN3-801580-A003-1		Revision C
	Issue Date 11/24/03	Revision Date 6/1/06	
	Plant Y-12	Page 1	of 1

Caster's Company Name			Supplier's Company Name		
Mixing Start Date	Time	Air Temp. °F	Thermal Ceramics Kaolite 1600™ Certificate of Conformance		
Kaolite 1600™ Mixing and Vibration Casting Information			Comments	Operator	Witness
50 lb. Bag ID Number					
Bag Wt.					
1.65 × Bag Wt.					
Mixing Control Number (MCN)[a]					
Water Wt. ±0.5 lbs. (1.65 times Kaolite Bag Wt.)					
Mix Finish Time					

[a] A 10-digit control number is recommended for the Mixing Control Number (MCN) consisting of the date and the time format using a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

EXEMPT FROM IO-155

Attachment B EQUIPMENT SPECIFICATION ES-3100 Shipping Package Body Weldment	Specification Number JS-YMN3-801580-A003-2		Revision C
	Issue Date 11/24/03	Revision Date 6/1/06	
	Plant Y-12	Page 1	of 1

Caster's Company Name			Seller's Company Name			
Part Serial Number			Body Weldment Drawing Number M2E801580A002			
Measured Weights ±0.5 lb	Casting Information		Comments		Operator	Witness
	Weight	Date				
Clean and Empty						
Filled with Water [a]						
Before Baking [f]						
After Baking Cycle 5						
After Baking Cycle 5A [d]						
After Welding						
Water Information	Water Weight ±0.5 lb	Water Temp.	Comments		Operator	Witness
Water Conditions [a]	lb	°F				
Casting Start Date	Air Temp. °F	Vibration Settings [b] lbf VPM				
Operation	MCN [e]	Time	Comments		Operator	Witness
Pour Start						
Pour Start						
Pour Start						
Vibration Start						
Vibration Stop						
Baking Cycle 5	Baking Control Num. [c]	Date	Time	Density [d]	Operator	Witness
Baking Cycle 5A [d]	Baking Control Num. [c]	Date	Time	Density [d]	Operator	Witness

[a] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[c] A 10-digit Baking Control Number shall be used to define the date and the time of baking using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[d] Use the above weights to calculate the Density as shown below. If the density is greater, then 25.4 lb/ft^3 then proceed with the next Baking Cycle. If the density is less then 19.4 lb/ft^3 then contact the Company for disposition.

$$\text{Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3\ \text{lb/ft}^3 \quad @\ 70°\text{F}$$

[f] Recommend Before Baking weight is to be 330 to 386 lb range.

EXEMPT FROM IO-155

Attachment C **EQUIPMENT SPECIFICATION** **ES-3100 Shipping Package** **Top Plug Assembly Vibration Casting Control**	Specification Number JS-YMN3-801580-A003-3		Revision C
	Issue Date 11/24/03	Revision Date 6/1/06	
	Plant Y-12	Page 1	of 1

Caster's Company Name			Seller's Company Name			
Part Serial Number			Top Plug Assembly Drawing Number M2E801580A008			
Measured Weights ±0.5 lb	Casting Information		Comments		Operator	Witness
	Weight	Date				
Clean and Empty						
Filled with Water [a]						
Before Baking [f]						
After Baking Cycle 5						
After Baking Cycle 5A [d]						
After Welding						
Water Information	Water Weight ±0.5 lb	Water Temp.	Comments		Operator	Witness
Water Conditions [a]	lb	°F				
Casting Start Date	Air Temp. °F	Vibration Settings [b] lbf / VPM				
Operation	MCN	Time	Comments		Operator	Witness
Pour Start						
Pour Start						
Vibration Start						
Vibration Stop						
Baking Cycle 5	Baking Control Num. [c]	Date	Time	Density [d]	Operator	Witness
Baking Cycle 5A [d]	Baking Control Num. [c]	Date	Time	Density [d]	Operator	Witness

[a] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[c] A 10-digit Baking Control Number shall be used to define the date and the time of baking using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[d] Use the above weights to calculate the Density as shown below. If the density is greater than 25.4 lb/ft³ then proceed with Baking Cycle 1A. If the density is, less then 19.4 lb/ft³ then contact the Company for disposition.

$$\text{Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3\ \text{lb/ft}^3\ @\ 70°\text{F}$$

[f] Recommend Before Baking weight is to be 29.2 to 34.2 lb range.

EXEMPT FROM IO-155

Attachment D **EQUIPMENT SPECIFICATION** **ES-3100 Shipping Package** **Furnace and Baking Control**	Specification Number JS-YMN3-801580-A003-4		Revision C
	Issue Date 11/24/03	Revision Date 6/1/06	
	Plant Y-12	Page 1	of 1

Baking Company Name				Seller's Company Name			
Baking Control Number [a]				Furnace Serial Number			
Bake Start Date		Air Temp. °F		Computer Data File Name [b]			
Baking Process Control	Furnace Check or NA	Start Time	Start Date	Stop Time	Stop Date	Operator	Witness
Baking Cycle (1) 200°F for 4 hrs.							
Baking Cycle (2) 275°F for 1 hrs.							
Baking Cycle (3) 350°F for 1 hrs.							
Baking Cycle (4) 425°F for 1 hrs.							
Baking Cycle (5) 500°F for 36 to 46 hrs. [c]							
Baking Cycle (1A) 200°F for 4 hrs.							
Baking Cycle (2A) 275°F for 1 hrs.							
Baking Cycle (3A) 350°F for 1 hrs.							
Baking Cycle (4A) 425°F for 1 hrs.							
Baking Cycle (5A) 500°F for 4.5 to 5.5 hrs. [c]							

[a] Record the Baking Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.) on Casting Forms B, C, and F for each part baked under this furnace heating cycle.

[b] The sample baking cycle time and temperature data could be presented both in a digital and graphical form. For example, an Excel file showing the original data and time verses temperature plots shall be acceptable.

[c] Calculate the density as shown on Forms B or C following this furnace heating cycle phase. If the part density is greater than 25.4 lb/ft^3, then proceed with the remaining furnace phases.

EXEMPT FROM IO-155

Attachment E	Specification Number JS-YMN3-801580-A003-5		Revision C
EQUIPMENT SPECIFICATION **ES-3100 Shipping Package** **Wet Density Mixer Time Vibration Casting**	Issue Date 11/24/03	Revision Date 6/1/06	
	Plant Y-12	Page 1	of 1

Caster's Company Name			Seller's Company Name		
Mixer Make and Model					
Wet Mix Density Qualification Number [a]			Mix Control Number [a]		
Measured Weights ±0.5 lb	**Casting Information**		**Comments**	**Operator**	**Witness**
	Weight [c, b] (lb)	**Date**			
Clean and Empty					
Filled with Water [b]					
Water Information	**Water Weight [c, b] ±0.5 lb**	**Water Temp.**	**Comments**	**Operator**	**Witness**
Water Conditions		°F			
Casting Start Date	Air Temp. °F	Vibration Settings [c] lbf VPM	Mixer Speed Setting		
Operation	**Weight [c, b] (lb)**	**Time (min)**	**Wet Density [d] (lb/ft^3)**	**Operator**	**Witness**
Wet Cast [c]		1.0			
Wet Cast [c]		2.0			
Wet Cast [c]		3.0			
Wet Cast [c]		4.0			
Wet Cast [c]		5.0			
Wet Cast [c]		6.0			
Wet Cast [c]		7.0			
Wet Cast [c]		8.0			
Wet Cast [c]		9.0			
Wet Cast [c]		10.0			
Wet Cast [c]		11.0			
Wet Cast [c]		12.0			
Wet Cast [c]		13.0			
Wet Cast [c]		14.0			
Wet Cast [c]		15.0			
Curve fit the Time required to generate the target density and contact the Company for confirmation.			Target Density 56.2 lb/ft^3		

[a] Record the Wet Mix Density Qualification Number and the Mix Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.).

[b] Record water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Use both steel pails to calculate the weights and density.

[d] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[e] Use the above weights to calculate the Wet Density as shown below.

$$\text{Wet Density} = \frac{(WetCast - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3\ \text{lb/ft}^3\ @\ 70°F$$

EXEMPT FROM IO-155

Attachment F	Specification Number		Revision
EQUIPMENT SPECIFICATION	JS-YMN3-801580-A003-6		C
ES-3100 Shipping Package	Issue Date	Revision Date	
Baked Qualification Density Sample Vibration Casting	11/24/03	6/1/06	
	Plant	Page	of
	Y-12	1	1

Caster's Company Name			Seller's Company Name			
Mixer Make and Model						
Baked Qualification Density Number [a]			Mix Control Number [a]			
Measured Weights ±0.5 lb	**Casting Information** Weight ±0.5 lb	Date	**Comments**		**Operator**	**Witness**
Clean and Empty						
Filled with Water [c]						
Before Baking						
After Baking Cycle 5						
Water Information	**Water Weight ±0.5 lb**	**Water Temp.**	**Comments**		**Operator**	**Witness**
Water Conditions [c]		°F				
Casting Start Date	Air Temp. °F	Vibration Settings [b] lbf VPM				
Operation	MCN	Time	**Comments**		**Operator**	**Witness**
Pour Start						
Vibration Start						
Vibration Stop						
Baking Cycle 5	Baking Control Num.	Date	Time	Density [d]	Operator	Witness

[a] Record the Baked Qualification Density Number and the Mix Control Number in MMDDYYTIME (with time the 24 hour format i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.).

[b] Recommended Vibration settings are at 450 VPM and twice the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 120 pound-force.

[c] Record water weight and water temperature within 10 minutes from completion of the weighing process

[d] Use the above weights to calculate the Qualification Sample Density as shown below. If the density is greater then 23.4 lb/ft^3 or less then 21.4 lb/ft^3 contact the Company for disposition.

$$\text{Qualification Density} = \frac{(AfterBaking - CleanAndEmpty)}{(WithWater - CleanAndEmpty)} \times 62.3\ \text{lb/ft}^3 \quad @\ 70°\text{F}$$

EXEMPT FROM IO-155

APPENDIX 1.4.5

EQUIPMENT SPECIFICATION, JS-YMN3-801580-A005, *CASTING CATALOG NO. 277-4 NEUTRON ABSORBER FOR THE ES-3100 SHIPPING PACKAGE*

EQUIPMENT SPECIFICATION APPROVAL/REVISION PAGE

SPECIFICATION NO. JS-YMN3-801580-A005	REV. F	ISSUE DATE 02-18-05
PAGE i of ii	REVISION DATE 10/12/2006	
PROCURED BY BWXT Y-12 L.L.C.	INSTALLED BY BWXT Y-12 L.L.C.	
PROJECT TITLE ES-3100 Shipping Package	PLANT Y-12	BUILDING AREA
JOB TITLE Production Design Definition	W.O. OR E.S.O. 7RCPCA08	RECORD NUMBER Y2003-0328
SPECIFICATION FOR Casting Catalog No. 277-4 Neutron Absorber For The ES-3100 Shipping Package		SSC IDENTIFICATION NUMBER NA

APPROVALS

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY G. A. Byington /s/	2/18/05	PROJECT ENGINEER G. A. Byington /s/	2/18/05
DESIGN VERIFICATION M. L. Goins /s/	2/18/05	CRITICALITY SAFETY D. A. T. J. F. DeClue /s/	2/18/05
DISCIPLINE MANAGER D. P. Sooter /s/	11 Feb 05		

REVISIONS/APPROVALS

REV. NO.	DESCRIPTION OF REVISION
A	Issued for Procurement.
B	Changed the minimum LOD from 25.3% to 30.1% at three locations on page 13 section 4.7.3 and one location on page 23 Form D.
C	General changes. Went from an off the shelf item to a two part system of boron carbide plus high alumina cement.
D	General revision. Reformatted sections and attachments. Deleted references to drawing numbers.
E	The mass limits were changed to account for volume tolerances in the 277-4 annulus. Section 3.3.8, Item I, "inner liner" was replaced with "can". A.3.1 was separated into two sections; the second part of A.3.1 became A.3.1.a with the title "Net Count Rate Time Determination". Section A.6.3 was modified by adding "Define the repeatable accuracy for" before the first sentence. JS-YMN3-801580-A005-5 was expanded to include more approval data requirements. A typo was fixed on JS-YMN3-801580-A005-6. Added Rev level to Forms and headers.
F	In Section 3.3.9.3, added maximum and minimum LOD% table based upon cured density and made reference to table on Form F.

SIGNATURE	DATE	SIGNATURE	DATE
PREPARED BY G. A. Byington /s/	10/11/06	PROGRAM MANAGER George Singleton /s/	11/21/06
DESIGN VERIFICATION Monty L. Goins /s/	11/07/06	CRITICALITY SAFETY John F DeClue /s/	11/16/06
DISCIPLINE MANAGER W. I. North /s/	11/21/06	QUALITY ASSURANCE Vaughn Chase /s/	11-20-2006

This document has been reviewed by a Y-12 DC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner /s/ Date: 11/8/06

EXEMPT FROM IO-155 (8-02)

CONTENTS

ATTACHMENTS

1.0 Scope

1.1 This specification describes the requirements for the procurement, preparation, casting, and verification of a neutron absorber material into the ES–3100 shipping package. The neutron absorber material shall be cast into ES–3100 Body Weldment (Figure 1), Neutron Absorber Form (Figures 4 and 5), Heavy Can Spacer Assembly (Figure 6), and 10 oz. double frication can(Figures 7 and 8) with tooling, i.e., Neutron Absorber Casting Funnel Assembly (Figure 2), and Body Weldment and Casting Funnel Assembly (Figure 3).

1.2 Definitions

277-0 - Thermo Electron's Catalog No. 277-0, Heat Resistant Shielding "Non-Borated" high alumina cement.

277-4 - A mixture of 277-0 and boron carbide (B_4C) powder to form a neutron absorber material.

Companion Sample Cans - The 10 oz. double friction cans in Figures 7 and 8 used for sampling.

Company - BWXT Y-12 L.L.C.

Dry Batch - A dry mix of batch size of 277-4.

Dry Blend Batch - A thoroughly mixed Dry Batch.

Heavy Can Spacer Assembly - The 10 oz. double friction can in Figure 6.

Overcast – Additional cast material required to achieve the fill requirements.

PGNAA Subcontractor – Independent testing firm that performs the Prompt Gamma-ray Neutron Analysis on the companion sample cans for the Company.

Process Procedures - Dry mixing, wet mixing, casting, sampling, and inspection procedures.

Subcontractor - The manufacturer of the ES-3100 Drum Assembly per JS-YMN3-801580-A001.

Vibration Casting – Vibration during casting to remove the air bubbles.

Wet Mix Batch - A wet mix of Dry Blend Batch and water.

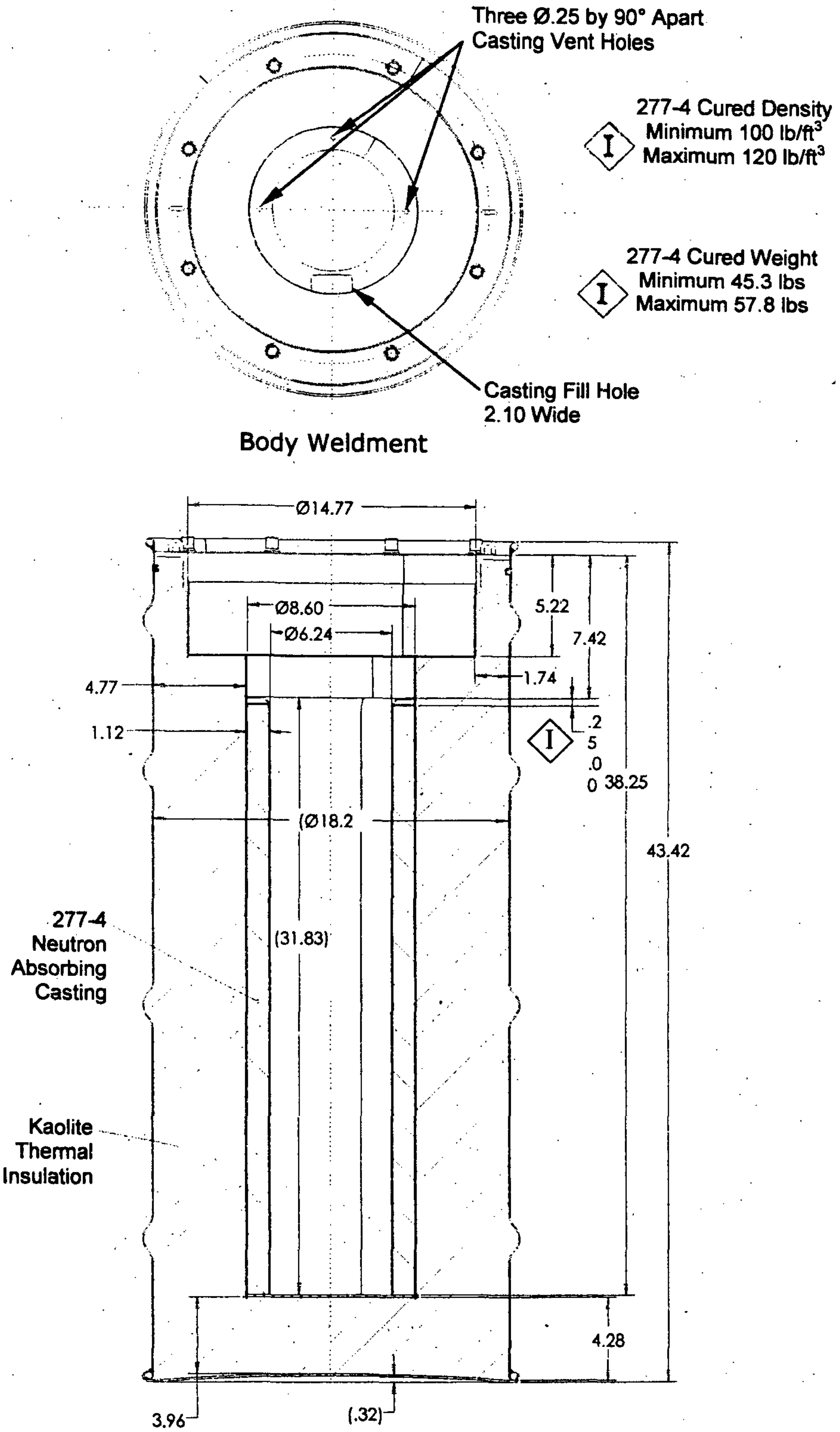
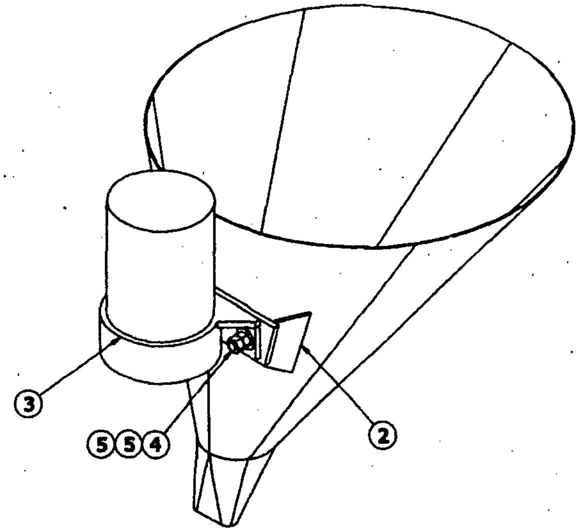


Figure 1 ES-3100 Neutron Absorbing Casting

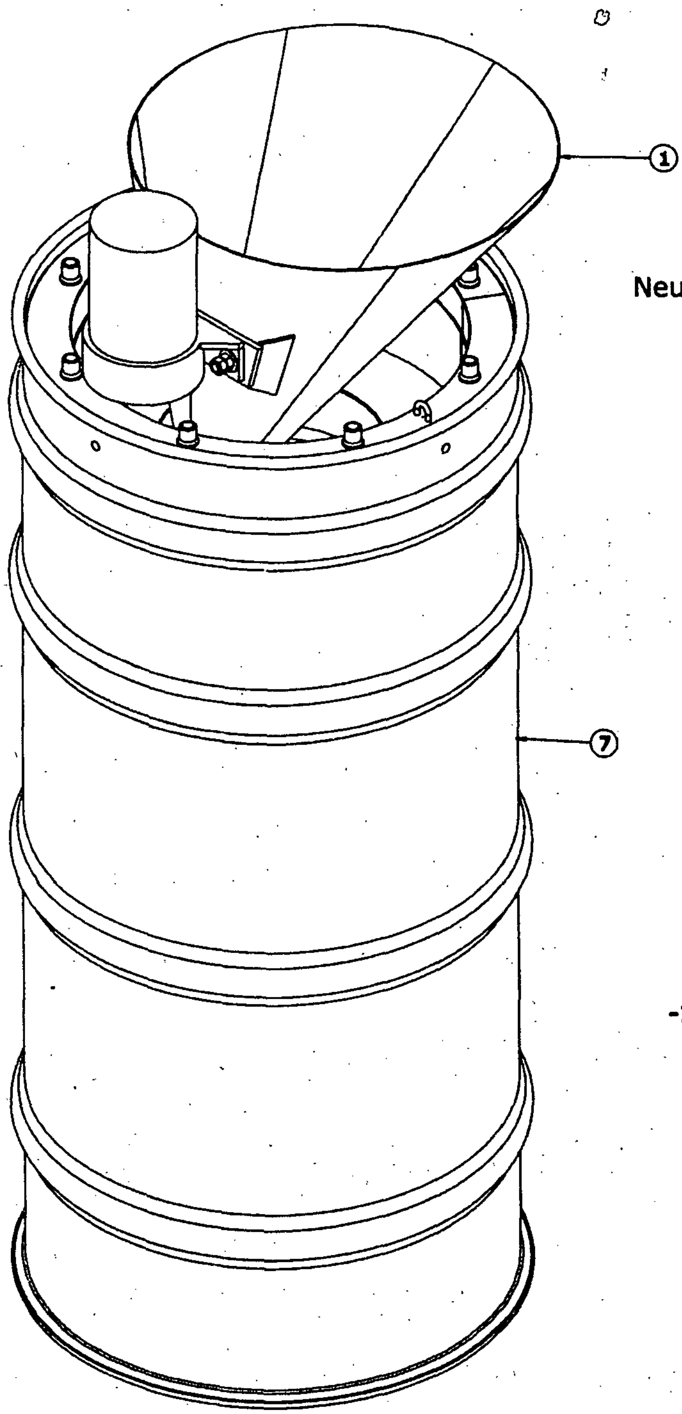
Neutron Absorber Casting Funnel Assembly



-1 NEUTRON ABSORBER CASTING FUNNEL ASSEMBLY

VIBRATOR POWERED CASTING FUNNEL

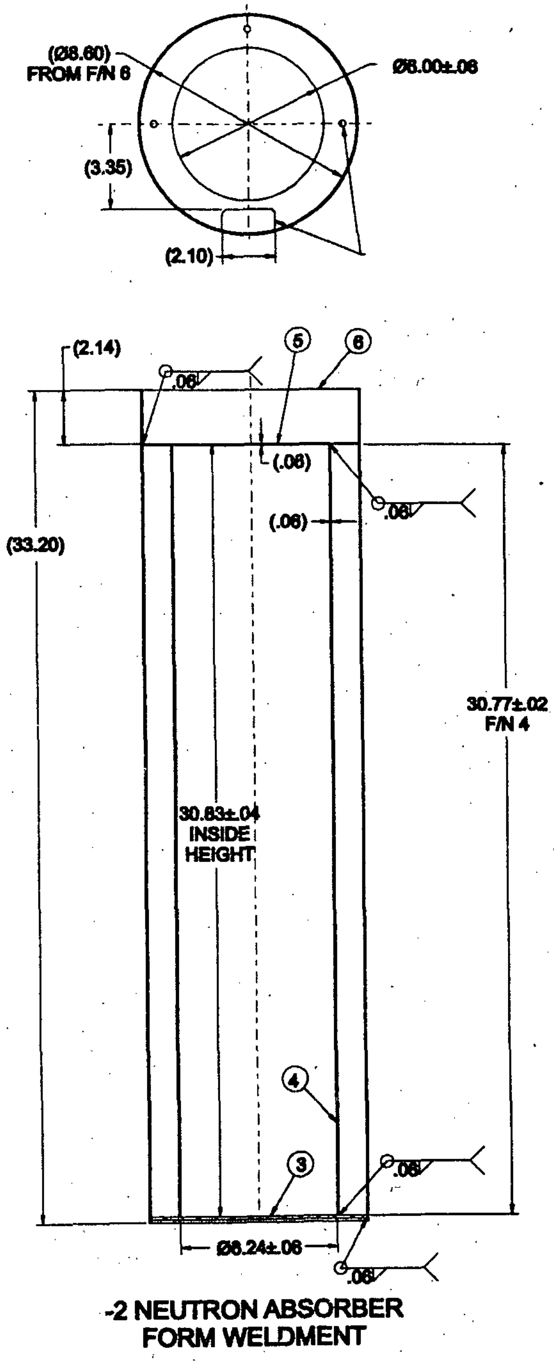
Figure 2



-6 BODY WELDMENT AND CASTING FUNNEL ASSEMBLY

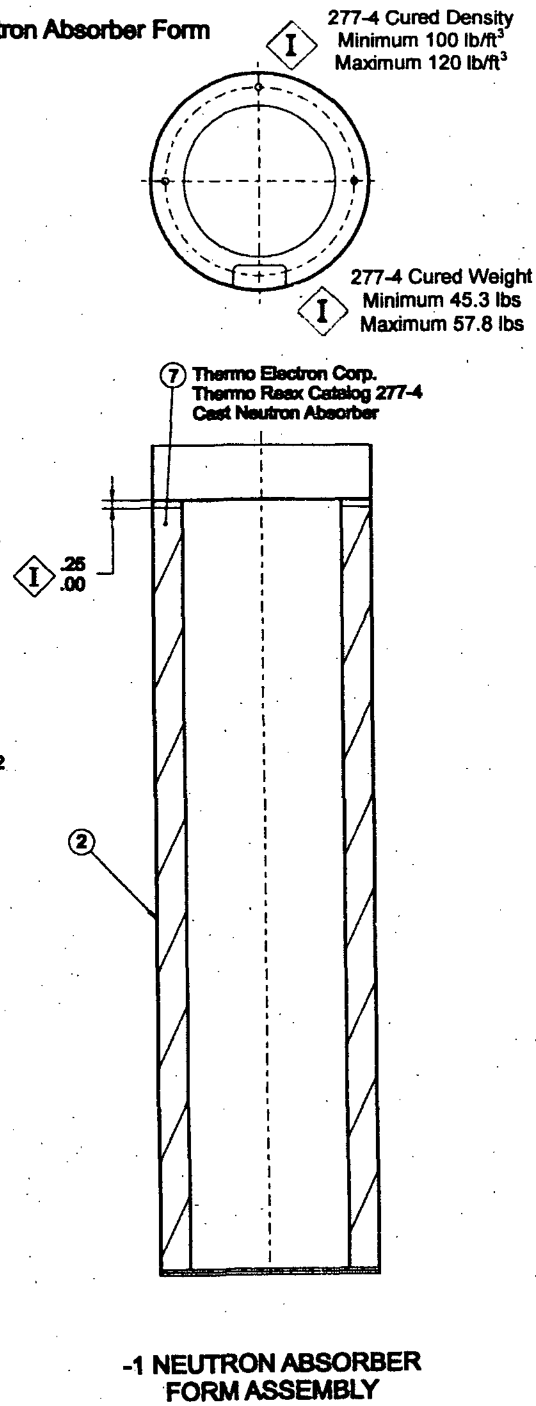
Figure 3

Neutron Absorber Form



-2 NEUTRON ABSORBER FORM WELDMENT

Figure 4



-1 NEUTRON ABSORBER FORM ASSEMBLY

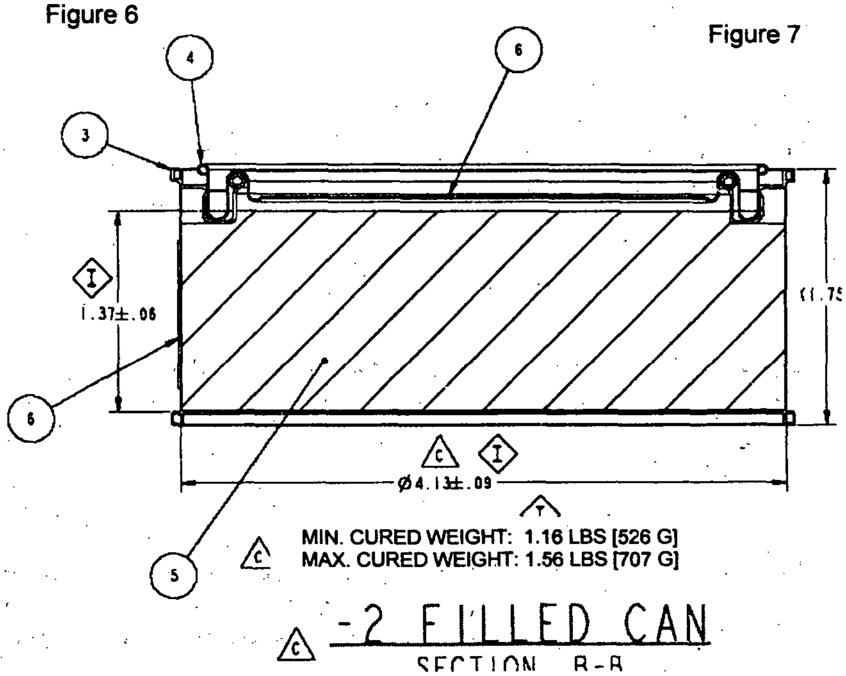
Figure 5

HEAVY CAN SPACER ASSEMBLY

Figure 6

10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 7



10oz DOUBLE FRICTION CAN
FILLED WITH 277-4

Figure 8

2.0 Applicable Documents

2.1 The following documents are a part of this specification. When there is a conflict between the specification and the applicable documents, the Subcontractor shall bring it to the attention of the Company for resolution.

2.2 Standards

ASTM A 380-99	*Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems*
ASTM C 750-03	*Specification for Nuclear-Grade Boron Carbide Powder*
ASTM C 791-04	*Test Methods for Chemical, Mass Spectrometric, and Spectrochemical Analysis of Nuclear-Grade Boron Carbide*
ASTM E 11-04	*Standard Specification for Wire Cloth and Sieves for Testing Purposes*
10 CFR 71 Subpart H	*Code of Federal Regulations - Energy - Packaging and Transportation of Radioactive Material - Quality Assurance*

2.3 Company Documents

JS-YMN3-801580-A002	*ES-3100 Drum Assembly*
JS-YMN3-801580-A003	*Manufacturing Process Specification for Casting Kaolite ™ Into the ES-3100 Shipping Package*
M2E801580A026	*Heavy Can Spacer Assembly*

2.4 Referenced Documents (Not Provided with Request for Proposal)

DAC-PKG-801624-A001	*Mixing Weights And Elemental Composition of 277-4 Neutron Poison used in the ES-3100*
Ltr. No. COR-NDA-04-93	Canberra Oak Ridge, LLC, January 5, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis and Neutron Transmission Measurements on Prototype Confinement Vessel Inner Liners and Spacers.*
Ltr. No.: COR-NDA-05-015	Canberra Oak Ridge, LLC November 3, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis On 20 Slip Fit Spacer Cans.*

3.0 Requirements

3.1 General Requirements

The Subcontractor shall be responsible for supplying all materials, services, facilities, and equipment to meet the requirements of this specification unless otherwise noted. Items needed to meet the requirements of this specification that are not identified in this specification shall be specified by the Subcontractor and submitted as Approval Data.

3.2 Equipment Requirements

3.2.1 Certified Scales

All weighing operations of assemblies and materials shall be conducted on certified scales with a minimum accuracy of ±1% of the required measurement or as specified by the measurement tolerance. Scale certification shall be submitted as Approval Data.

3.2.2 Dry Blending the 277-0 and B_4C

A small parts tumbler shall be used to dry blend the ingredients. The small parts tumbler shall be a Multi-Barrel Small Parts Tumbler Benchtop Base (McMaster-Carr No. 44235A11) with Multi-Barrel Small Parts Tumbler 8 Gallon Barrel, 15-3/4" Dia X 14-3/4" W (McMaster-Carr No. 44235A24) or Company approved equal.

3.2.3 Mortar or Plaster Mixer

A mortar or plaster type mixer with moving vanes to shear the wet mix shall be used. The batch volume is approximately 0.5 ft^3 (15 quarts or 3.8 gallons). Therefore, it is recommended that the mixer volume should be 1.5 to 2 times the mix volume or around 0.75 to 1.0 ft^3 (22.5 to 30 quarts, ~6 to 8 gallons). The 277-4 wet mix is thixotropic when mixed and it is recommended that a heavy duty adjustable vibrator mounted to the mixer for both mixing and pouring is used.

3.2.4 Small Plaster Mixer

A drill-powered mortar or plaster mixer and a 5-gallon plastic bucket may be used on small batches of 277-4 instead of the mortar or plaster type mixer. The 5-gallon plastic bucket shall be placed upon the Heavy Duty Drum Vibrator (see Section 3.2.6).

3.2.5 Vibration Powered Funnel Assembly

The Neutron Absorber Casting Funnel Assembly with a vibration- powered funnel (Figures 2 and 3) shall fill both the Body Weldment (Figure 1) and the Neutron Absorber Form (Figure 4). The Casting Funnel Assembly may be modified as required by the Subcontractor to get the wet mix to flow.

3.2.6 Heavy Duty Drum Vibrator

A Heavy Duty Drum Vibrator/Packer shall be used to hold the Body Weldment (Figure 1) or Neutron Absorber Form (Figure 4) for vibration casting the 277-4 into the stainless steel forms. The Heavy Duty Drum Vibrator/Packer shall be McMaster-Carr No. 5809K11, or Company approved equal.

3.2.7 Bench Vibrator

A bench vibrator shall be used during the mixing of the companion sample cans and Heavy Spacer Can Assemblies. The bench vibrator shall be Tabletop Vibration/Mixing Table 10-in. by 7-in. Platform, 10-lb Capacity Continuous Use (McMaster-Carr No. 5714K61) or Company approved equal.

3.3 277-4 Neutron Absorber

3.3.1 Raw Casting Material Requirements and Inspection

3.3.1.1 277-0

Thermo Electron Corporation Catalog No. 277-0 Heat Resistant Shielding "Non-Borated" shall be procured. The manufacturer model or catalog number and expiration date shall be clearly indicated on the container. A Certificate of Conformance shall be provided with each lot or batch. The Certificate of Conformance shall include the lot or batch number and the expiration date. The 277-0 shall be sealed and stored in a dry place.

3.3.1.2 Type 1 Nuclear-Grade Boron Carbide Powder

B_4C powder shall be procured as Type 1 Nuclear-Grade Boron Carbide Powder per ASTM C 750. 100% of the powder shall pass through a No. 140 Sieve per ASTM E 11. A Certificate of Conformance and a copy of the chemical and elemental analysis purity in accordance with ASTM C 791 shall be provided.

3.3.1.3 Water

The water shall be potable, filtered through a 20-micron filter and an activated charcoal filter, have a chlorine content of less than 4 ppm, and have a temperature of 65±15°F. Unfiltered potable water may be used for the cleaning of equipment used to cast the neutron absorber system.

3.3.2 Dry Blending Process

3.3.2.1 Dry Batch

A dry batch of 277-4 shall be a mixture of 93.6 wt% 277-0 and 6.4 wt% B_4C. It shall be of sufficient quantity to fill one ES-3100 Body Weldment or Neutron Absorber Form, i.e., approximately 0.55 ft^3 poured volume and 50 lbs. of dry 277-4 weight. The batch size may be adjusted as necessary based on experience for the ES-3100 Body Weldment or Neutron Absorber Form. The tolerance for 277-0 and B_4C weighting shall be the following:

277-4 Dry Batch Size	277-0	B_4C
Equal to or greater than 30 lbs.	±.2 lbs.	±.01 lbs.
Less than 30 lbs	±.01 lbs.	±.01 lbs.

The data shall be recorded on Form A.

3.3.2.2 Blended Dry Batch

The dry batch of 277-4 shall be thoroughly blended. The data shall be recorded on Form A.

If the blended dry batch is not used immediately, the blended dry batch shall be sealed and stored in a dry place with a Blended Dry Batch control number attached to the container.

The Blended Dry Batch shall not be used if the 277-0 expiration date has expired.

3.3.3 Wet Mixing

The weight of the dry mix and water shall be to the following weight proportions of 100% dry mix and 27±1% water. The 277-4 is thixotropic when mixed. It is recommended to have a heavy duty adjustable vibrator mounted to the mixer for both mixing and pouring. Place the water in the mixer and add the dry mix into the water. Before casting, mix the dry powder and water for at least 3 minutes and less than 60 minutes. Any material in the mixer after 60 minutes shall be discarded. Mix only in a room with a temperature range of 70±25°F.

The data shall be recorded on the appropriate form, i.e., Form B for overcast, Form C for Body Weldment, Form D for Neutron Absorber Form, and Form E for Heavy Can Spacer Assembly/PGNAA Acceptance Standards.

3.3.4 Body Weldment and Neutron Absorber Form Vibration Casting

3.3.4.1 Vibration Casting Requirements for Body Weldment and Neutron Absorber Form

During the vibration casting of the 277-4, record the Body Weldment (Figure 1) casting data on Form C and the Neutron Absorber Form (Figure 5) casting data on Form D. A stainless steel vibration powered funnel (i.e., Neutron Absorber Funnel Assembly shown in Figure 3) fits inside the 2.10-in. wide slotted fill hole shown in Body Weldment and in Neutron Absorber Form.

a. Weigh and record the data on Form C or on Form D.
b. Weigh and record the water weight and temperature data when filled with water to within .25 in. of the top metal surface.
c. Remove the water.
d. Secure the part on the drum vibrator.
e. Plug the 6.24 in. diameter cavity to keep the wet mix from falling into the liner bottom.
f. Place the Neutron Absorber Funnel Assembly in the slot and secure in place. If required, additional vibrators may be added.
g. Prepare the Wet Mix per Section 3.3.3.
h. Start the drum vibrator.
i. Scoop the wet mix into the Neutron Absorber Funnel Assembly.
j. Turn on the vibrating funnel and adjust the vibration force until the wet mix flows.
k. About half way through filling the wet mix in either the Body Weldment or Neutron Absorber Form, cast two companion samples for Section 3.3.7. Record the companion sample data on Form F and either Form C or Form D.
l. Continue filling the wet mix until the part will take no more.
m. After filling is complete, vibrate the container for 45±15 seconds to remove air bubbles.

3.3.4.2 Overcast Requirements for Body Weldment and Neutron Absorber Form

A few hours after casting, the 277-4 will settle in the vertical direction and leave a layer of watery fluid on the top of the casting. Remove this fluid and overcast the top between 4 and 24 hours from the first casting. After the overcast has cured for between 4 and 24 hours inspect the depth of casting to the top metal surface and verify that it is within 0.25 in. If not within the 0.25 in., cast additional 277-4 material and perform the following:

a. Remove the water.
b. Secure the Body Weldment or Neutron Absorber Form on the drum vibrator.
c. Plug the 6.24 in. diameter cavity to keep the wet mix from falling into the liner bottom.
d. Record the Overcast Wet Mix Control Number (WMCN) on the appropriate casting data form.
e. Prepare the Wet Mix per Section 3.3.3.
f. Start the drum vibrator.
g. Scoop the wet mix into the Body Weldment or Neutron Absorber Form Assembly until the vent hole is filled.

The final shrinkage of the 277-4 shall be within 0.25 in. of the metal surface as shown in Figures 1 and 5.

3.3.4.3 Curing Requirements Body Weldment and Neutron Absorber Form

Cover the newly cast wet component with plastic or metal for 7 days. Do not store the cast 277-4 castings in temperatures below 35°F for the first 30 days after casting.

After 7 days, remove the plastic or metal cover and dehydrated using either or both vacuum and heat to create an acceptable density and weight. If heat is used, the maximum temperature of the inner liner shall not exceed 250°F.

Record the diamond I measurements shown on Figures 1 and 5 on the appropriate casting data forms. The acceptable cured height measurement shall be less than 0.25 inches. The acceptable cured casting weight shall be between 45.3 and 57.8 lbs. Cured casting weights shall be used to calculate the cured density. If the cured casting density is greater than 120 lb/ft^3, continue the dehydration process. If the cured casting density is less than 100 lb/ft^3, the casting shall be unacceptable, the appropriate form shall be completed, and a copy of the form shall be sent to the Company.

3.3.5 Heavy Can Spacer Assembly

The Heavy Can Spacer Assembly shown in Figure 6 shall be the 10-oz. double friction metal can as shown in Figures 7 and 8. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured cast density of 100 to 120 lb/ft^3 and a cured weight range of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

Two cans from the middle of the lot on Form E, i.e., a maximum lot of 22 cans, shall be selected and identified as companion sample cans. Cans that are not from the middle of the lot on Form may be selected with Company approval.

3.3.6 PGNAA Acceptance Standards

The PGNAA Acceptance Standards shall be made with a Company representative witnessing the manufacturing processes of weighing, blending, wet mixing, and casting. The PGNAA Acceptance Standards shall be the 10-oz. double friction metal can as shown in Figures 7 and 8. The cured casting weight for each can shall be measured and the cured casting density recorded on Form E. A cured casting density of 100 to 120 lb/ft^3 and a cured casting weight of 1.16 to 1.56 lbs shall be acceptable. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company.

One can from the middle of the lot on Form E, i.e., a maximum lot of 22 cans, shall be selected and identified as a companion sample can for Loss On Drying (LOD) testing. The remainder of the lot shall be sent to the PGNAA Subcontractor.

3.3.7 Companion Sample Cans

In addition to the companion sample cans selected in Sections 3.3.5 and 3.3.6, two companion sample cans shall be made half way through the casting process for the Body Weldment and the Neutron Absorber Form per Section 3.3.4.1. Companion sample can data shall be recorded on Test Form F.

a. The cured casting density of all companion sample cans shall be calculated per Section 3.3.9.2 and recorded on Form F. If the cured casting density is outside the acceptable range, a copy of the form shall be sent to the Company. A low cured casting density of a companion sample can shall not be a reason to reject the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly casting lot, or PGNAA Acceptance Standards casting lot.
b. The odd serial number companion sample cans for the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly casting lot, or PGNAA Acceptance Standards casting lot shall be LOD tested to verify the hydrogen content per Section 3.3.9.3.
c. The even serial number companion sample cans for the Body Weldment, Neutron Absorber Form, or Heavy Can Spacer Assembly casting lot shall be PGNAA tested to verify the ^{10}B content per Section 3.3.9.4.

3.3.8 Casting the 10 oz. Double Friction Metal Cans

a. Select a labeled can which has a drawing and serial number per drawing M2E801580A026.
b. Weigh the empty labeled can and lid and record the casting can data on Forms C, D, or E. It is acceptable to weigh ten cans with ten lids for each purchase order of cans and to use the average can and lid weight on each form.
c. Weigh the water and measure the water temperature. Record this data on Form C, D, or E. Fill with water only up to the bottom of the inside rim. The can lid shall be on the scale. It is acceptable to weigh the water weight of the first ten cans with ten lids of the same lot of cans and to use the average water weight for each of the following cans if the measurements are consistent.
d. Remove the water from the cans.
e. Prepare the Wet Mix Batch following Section 3.3.3.
f. Hold the can on the bench vibrator during filling with the 277-4 wet mix. Quickly vibrate and continue to add wet mix to the can lip.
g. Once all of the cans are full of wet mix, return the first can back to the vibrator for at least 3 minute at a high frequency setting. During the 3 minutes of vibration, continue to add 277-4 wet mix until the can stays full. Repeat this process for all the cans in the casting lot.
h. Between 1 to 24 hours after casting, scrape the top of the casting to within 0.19±0.03 from the can rim.
i. Clean the can rim around the edge per Section 3.4.2.

j. Perform an in-process measurement of the scraped casting height to ensure that the casting height parameters are met shown in Figure 8.
k. Cover the casting by placing the properly labeled can lid on the can for 7 days.
l. Remove the can lid and let the can air dry or use either or both vacuum and heat to create an acceptable density and weight. If heat is used, the maximum temperature of the can shall not exceed 250°F.
m. Measure casting height and weigh the can with lid. Record this data on Forms C, D, or E.
n. Record the final Companion Sample Can casting density, weight, or casting height measurements data on Form F.

3.3.9 Verification

All verification shall be completed after the casting is cured.

3.3.9.1 Cured Casting Density Verification

The density of cured casting in the Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly, and PGNAA Acceptance Standards shall be determined by weighing the casting container before casting, while filled with water, after casting, and when cured.

Since the density of water is known, a simple relationship between the weight differences shall determine the cured casting density.

$$Density = \left(\frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \text{ lb/ft}^3$$

3.3.9.2 Companion Sample Can Cured Casting Density Verification

The density of cured casting in each companion sample can shall be determined by weighing the can before casting, while filled with water, after casting, and when cured.

Since the density of water is known, a simple relationship between the weight differences shall determine the cured casting density.

$$Density = \left(\frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3 \text{ lb/ft}^3$$

3.3.9.3 Companion Sample LOD Verification

The companion sample cans identified in Section 3.3.7.b shall be LOD tested. The acceptable LOD percent range shall be based upon the companion sample can cured casting density in Section 3.3.9.2. The Acceptable Maximum and Minimum LOD% at Density is given in this table below. This table was developed from data in DAC-PKG-801624-A001, Table 7.

Acceptable Maximum and Minimum LOD% at Density		
Density (lb/ft^3)	Maximum LOD%	Minimum LOD%
100	31.80%	28.61%
101	32.47%	28.33%
102	33.12%	28.06%
103	33.77%	27.79%
104	34.40%	27.52%
105	35.03%	27.26%
106	35.64%	27.00%
107	36.25%	26.75%
108	36.84%	26.50%
109	37.42%	26.25%
110	37.99%	26.01%
111	38.56%	25.78%
112	39.11%	25.55%
113	39.65%	25.32%
114	40.18%	25.10%
115	40.70%	24.88%
116	41.21%	24.66%
117	41.71%	24.45%
118	42.20%	24.25%
119	42.68%	24.05%
120	43.15%	23.85%

a. The lid shall have the serial number permanently transferred by vibro etch or other method.
b. The lid shall have a small vent hole in it. It is recommended that a nail be used to punch a hole 0.12±0.06 in. diameter in the metal lid from the inside surface of the lid.
c. Match the can serial numbers and place the lid on the can.
d. The weight of the can shall be recorded on Form F.
e. The cans shall be placed in an oven at 1500±150°F (800°C) for 4 hours.
f. The weight of the can shall be recorded on Form F with the can temperature not below 100°F.
g. Calculate the LOD% using the equation below and record it on Form F. Due to can oxidizing and gaining weight during the heating cycle, a 0.024 lb correction factor is included in the following LOD% calculation.

$$LOD\% = \left[1 - \frac{(LODWeight - Empty - 0.024lb)}{(Cured \;\&\; Clean - Empty)}\right] \times 100\%$$

h. Verify that the LOD% is within the acceptable range. If water content is outside the acceptable range, a copy of the form shall be sent to the Company.

3.3.9.4 PGNAA Verification

The companion sample cans identified testing in Section 3.3.7.c shall be sent to the PGNAA Subcontractor. The PGNAA Subcontractor will test to the requirements in Appendix A and record the data on Forms AA to AD. The PGNAA Subcontractor will send copies of the completed Forms AC and AD to the Subcontractor and Company.

The PGNAA testing acceptance results on From AD shall be transferred to Form F.

3.4 Cleaning Requirements

3.4.1 Contact with Chlorides or Fluorides

The stainless steel material shall be protected from contact with chlorides in accordance with ASTM A380, paragraph 8.5, during all operations including packaging. The Material Safety Data Sheet (MSDS) for all cleaning solutions or products used on the ES-3100 shall be submitted as Approval Data to verify that no chlorides or fluorides are present.

3.4.2 Satisfactory Cleanliness

Cleaning procedures for the stainless steel per Section 3.4 of equipment specification JS-YMN3-801580-A002 shall be submitted as Approval Data. Only non-chloride-bearing chemicals shall be used for cleaning (e.g., trisodium phosphate detergent or acetone). Water used in cleaning shall have a maximum chlorine content of 4 parts per million.

After casting but prior to packaging, stainless steel components of the forms and cans shall be cleaned per the approved cleaning procedures. Satisfactory cleanliness shall be determined by visual inspection as can be observed by a person with normal visual acuity (natural or corrected) and without magnification. Light intensity of at least 100 ft-candles shall be provided on the surface to be inspected.

4.0 <u>Quality Assurance</u>

4.1 Quality Assurance Program

The subcontractors shall have in place and maintain a Quality Assurance (QA) Program and inspection system that meets the requirements of 10 CFR 71 Subpart H. If not previously submitted, an uncontrolled copy of the subcontractor's QA Program shall be submitted as Offer Appraisal Data.

4.2 ES–3100 Casting Quality Assurance Requirements

4.2.1 ES–3100 Documentation Package

All records shall be identified based on the ES–3100 serial numbers. The ES-3100 Documentation Package shall be provided as Certified Data with each ES-3100 casting. The ES-3100 Documentation Package shall be complete, legible, indexed, and traceable to the material supplied and include the following:

a. Material measuring, dry blending, wet mixing, casting, sampling, and inspection forms, i.e, Forms A through F.

b. A Certificate of Compliance for each lot of the 277-0 Heat Resistant Shielding "Non-Borated" dry mix documentation with the expiration date identified on each container.

c. A Certificate of Compliances for B_4C powder to Type 1 Nuclear-Grade Boron Carbide Powder per ASTM C 750, chemical and elemental analysis per ASTM C 791, and 100% of the powder passes through a No. 140 Sieve per ASTM E 11.

d. A Certificate of Compliance signed by an officer of the Subcontractor confirming that the cast neutron absorber in ES−3100 shipping package meets the subcontract requirements.

4.2.2 Batch Processes

Batch processes such as mixing, pouring, curing, sampling, inspection, etc., shall be performed in accordance with detailed written procedures. These procedures shall specifically describe the exact manner in which these processes are to be performed. All records shall be traceable to the ES−3100 Shipping Package, Neutron Absorber Form, Heavy Spacer Can Assembly, PGNAA Acceptance Stands or Companion can serial numbers.

4.2.3 Materials Traceability

A manufacturing lot or batch number shall identify material furnished to make up the neutron absorber system. Materials shall be identified by material type; applicable specification and revision number, and be traceable to their lot numbers. Traceability records shall be available for review by the Company's representative.

4.2.4 Procedures

Preparation, installation, sample collection, and inspection processes shall be controlled and performed by qualified personnel. The procedures must incorporate a mechanism to identify process step completion. Procedures shall be submitted as Approval Data. The approved procedures shall be provided as Certified Data prior to the start of casting.

4.2.5 Training and Qualification of Personnel

The Subcontractor shall provide for the training and qualification of personnel to ensure their competence in the use of process procedures and specifications. Records of personnel qualifications shall be made available to the Company upon request. Only those personnel who have been qualified to perform a specific batch process used in the casting of Kaolite per equipment specification JS-YMN3-801580-A003 shall be used to perform work in this process.

4.2.6 The Company reserves the right to request any documentation and to witness any of the processes performed in accordance with this specification.

5.0 Preparation for Delivery

After cleaning of stainless steel surfaces per Section 3.4, aluminum foil duct tape shall be applied over the fill and vent holes in the Body Weldment (Figure 1) and the Neutron Absorber Form (Figure 5).

6.0 Manufacturer's Data

6.1 Offer Appraisal Data shall be submitted with the offer. This data shall become part of the subcontract requirements.

6.2 Approval Data will be reviewed and approved by the Company. Subcontractor shall not proceed with the casting activity until Company approval is given for all the Approval Data. The Approval Data shall be transmitted to the Company by the dates agreed to by the Subcontractor and the Company Subcontractor Administrator.

6.3 Certified Data will be used by the Company as the record for the ES-3100 shipping packages. The Certified Data shall be transmitted as noted.

6.4 A request for Company approved equal shall be submitted as Approval Data. Adequate information shall be provided with the request for Company approved equal so that the Company can determine if the item is equivalent.

ATTACHMENT A - Prompt Gamma-ray Neutron Activation Analysis Testing Setup & Tooling (Page 1 of 4)

A.1 Prompt Gamma-ray Neutron Activation Analysis Can Testing

Prompt Gamma-ray Neutron Activation Analysis (PGNAA) of boron performs one of the acceptances of the ES-3100 277-4 casting. Specifically, ^{10}B gives rise to a 478-keV gamma-ray produced by the recoil of the lithium nucleus from the neutrons captured in ^{10}B. The gamma-ray is Doppler broadened by 10–15 keV. The PGNAA shall be performed upon a companion sample can cast made during the drum casting in accordance with JS-YMN3-801580-A005 and Body Weldment (Figure 1), Neutron Absorber Form (Figure 5), Heavy Can Spacer Assembly (Figure 6), and the cast companion samples in the same 10-oz. double friction metal can on (Figures 7 and 8). PGNAA is a relative measurement therefore daily baselines are required to define the acceptance values.

Canberra Industries to perform the PGNAA testing.

Canberra Industries, Inc.
Linda C. Ostrowski
1133-C Oak Ridge Turnpike Suite 260
Oak Ridge, TN 37830-6442
865-241-3963 fax 865-241-3965

A.2 PGNAA Quality Assurances

The equipment and software used in the PGNAA shall be certified to a national standard.

A.3 PGNAA Measurements Setup

A PGNAA measurement setup number shall be required for each unique setup recording the pertinent data of the setup on Form AA. A new setup is required from previous prototypical work. Several setups may be tried to determine the most efficient testing setup. These changes shall be documented using Form AA. Once the setup is defined on Form AA reference the setup number each time it is used. Measure the PGNAA acceptance standards using the defined setup to verify the setup distances are repeatable within ±0.13-in.

A.3.1 Net Count Rate Measurements

Time shall be consistently applied throughout all of the PGNAA testing. For the prototype system setup, a time of at least 15 minutes (900 seconds) for each spectrum measurement was found to be satisfactory. A net count rate (NCR) in counts per second shall be used throughout with a set target standard time limit of around 900 seconds. Record both the count and time in seconds for that count on Form AA and calculate the count rate to three decimal places (i.e., 34.245 counts/sec).

A.3.1.a Net Count Rate Time Determination

The time of the measurement shall be determined by performing the Tooling Setup on Form AA at different times like 300, 600, 900, 1800, and 72000 seconds. Determine the accuracy effect of the total counting time on the counting statistics, based upon at least a 72000 seconds (20 hour) count. The testing time shall be re-evaluated when a significant change in the source system occurs.

A.3.2 Neutron Source

A spontaneous fission neutron source similar to the 1.8-µg ^{252}Cf prototype shall be used to perform the tests. This source was rated at 4.4×10^6 neutrons/sec on November 15, 2004. The neutron source is sealed in a 32.5-mm-long, 9.4-mm-diameter stainless steel cylinder and placed in a collimator.

ATTACHMENT A
(Page 2 of 4)

A.3.3 Collimator and Neutron Source Setup

A collimator similar to the prototype collimator shall be used to hold the source. The prototype collimator was a 3-in. cube of high-density polyethylene covered on five sides with 2 mm of cadmium as a neutron shield with at least 0.5-in. of lead on six sides as a gamma shield. The center of the sixth side of the polyethylene cube has a 9.5-mm hole into which the source was pressed. The sixth side is covered with cadmium except for a 1-in. square in the center. A 1-in. diameter hole in the cadmium at the source location shall be provided in the collimator to generate a better shaped neutron source for the sample can tests. The location of the collimator and source shall be defined in a fixture and shall be inspected to be repeatable to within ±0.13-in. to locate the collimator, can, detector, and other materials, e.g., polyethylene.

Record the setup and the results in the net detector count rate on Form AA. Record the setup source distance (SD) ±0.13-in. from the sample can lid. Move the filled sample can further away from the source, and repeat the process, increasing the distance in increments to identify the setup distance that maximizes the NCR for that source arrangement. Record the setup information on Form AA.

A.3.4 Detector

A detector system similar to the prototype shall be used. The prototype was a Canberra Model BE3825 Broad Energy Germanium (BEGe) detector, which was a gamma-ray detector, in a 2-in. thick lead shield with a Canberra Model 7935SL-7 cryostat and Canberra Model 2002CSL preamplifier to capture the gamma spectrum for the PGNAA measurements. This detector has a side lead shield but no shielding in the front to collimate the field-of-view. An Inspector 2000 along with the Genie2K gamma-ray analysis software package from Canberra was used for distinguishing the ^{10}B peak from the rest of the gamma-ray spectrum. It is recommended that a fixture be made to locate the collimator, can, and detector. Document the method used to determine the Compton boundary end points.

A.3.5 Detector Net Count Rate Determination

Use software equivalent to the Genie2K gamma-ray analysis software package from Canberra for performing the gamma-ray spectrum collection and analysis. The peak fitting routine in Genie2K does not expect a peak as broad as 10–15 keV; therefore, a region-of-interest (ROI) was set around the broad boron neutron activation peak of 478 keV. The data gathered has three components. The gross count is the total count of the gamma-rays detected with an energy that falls within the ROI. The Compton background is the portion of the gross count that is caused by scattered gamma-rays. The NCR is the portion of the total count that is from the boron in a period of time. The NCR is the difference between the gross and the Compton counts.

A.3.6 Detector Location Setup

The setup distance of the prototype detector setup was as close as possible using about 1-in. thick lead as a gamma shield to keep the detector noise signal low. This thickness was applied during the PGNAA documented in Ltr. No.: COR-NDA-05-015; Canberra Oak Ridge, LLC November 3, 2005, *Results of Prompt Gamma-ray Neutron Activation Analysis On 20 Slip Fit Spacer Cans*. Figure A.1 shows the direction this development work was heading. Document and verify that the detector setup distance (DD) from the sample can generates a maximum NCR by adjusting the detector setup distance and repeating this test. It is recommended that a fixture be made to locate the collimator, can, and detector.

ATTACHMENT A
(Page 3 of 4)

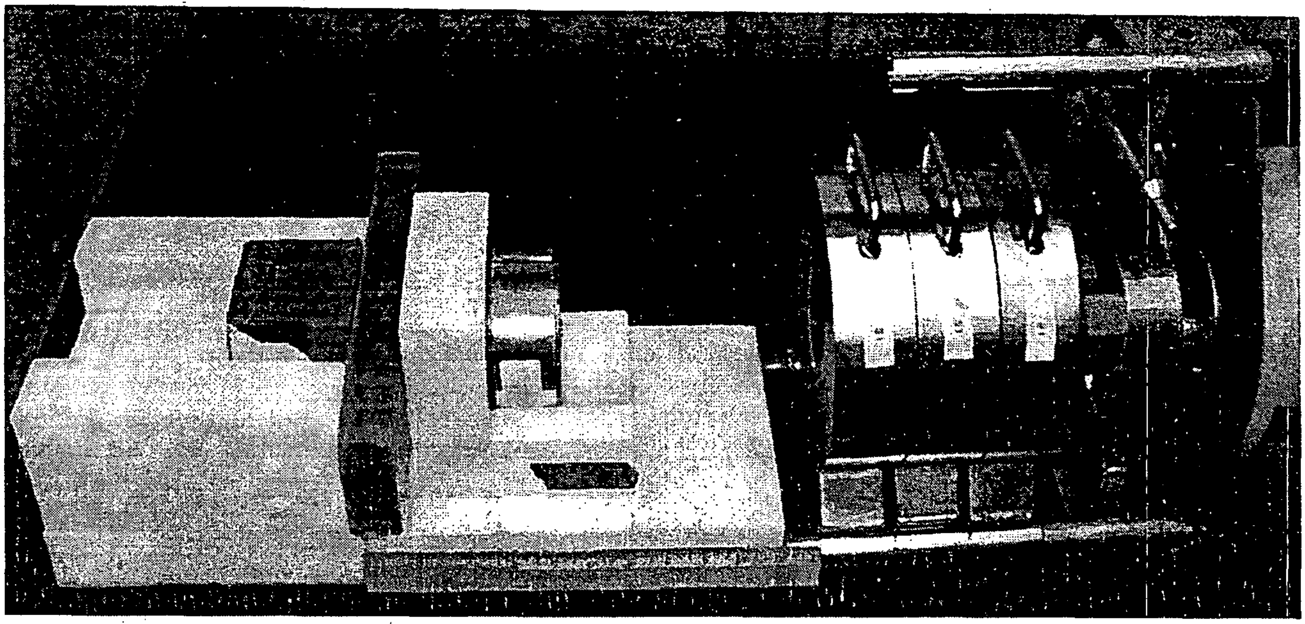


Figure A.1 Preliminary Tooling Generated for PGNAA

A.3.7 Detector Operation Setup

Set the detector setup distance (DD) ±0.13-in. and the setup source distance (SD) ±0.13-in. from the filled sample can. Record the set detector setup distance, setup source distance, 277-4 sample serial number, NCR value, and the day and time of the measurement in the setup form. Repeat this final test measurement in 30 minutes to verify the stability of the detector and this shall become the setup standard test measurement on Form AA. The repeatable measurement tolerances shall be part of the testing fixture certification inspection.

A.3.8 Net Count Rate Baseline Measurements

Once the setup is completed and the fixture dimensions are certified, Form AB shall be used to record the NCR for the twenty acceptance standards using the 10-oz. double friction metal cans. The baseline acceptance 277-4 NCR shall be set daily using five of the twenty acceptance standards using the 10-oz. double friction metal cans and recorded on Form AC. The twenty acceptance standards cans shall be inspected with a Company representative as a witness.

Select five PGNAA acceptance standards from Form AB as the Daily Standard Setup that generate approximately the same average and standard deviation as on Form AB. The baseline acceptance 277-4 NCR shall be set daily using five of the twenty acceptance standards using the 10-oz. double friction metal cans and recorded on Form AC. Verify the Daily Standard cans selection with the Company. The Body Weldment (Drum), Neutron Absorber Form (From), and Heavy Can Spacer Assembly (Lot) acceptance criteria for the ^{10}B interaction is based upon this test. The Minimum acceptable standard NCR shall be set daily using the following formula.

Minimum Acceptable NCR = Can Five NCR Average − 3 × Standard Deviation Can Five NCR

ATTACHMENT A
(Page 4 of 4)

A.4 Net Count Rate Acceptance Measurements

The NCR acceptance measurement shall be made following the Daily Standard Setup using Form AC and calculating a Pass Rate. Record the PGNAA setup number, day and start time of the measurement, the associated Body Weldment, Neutron Absorber Form, Heavy Can Spacer Assembly Lot's serial number, companion sample can serial number, actual net count, acceptable net count, and testing results on the inspection form. For the testing results, if the actual NCR is equal or above the Pass Rate, then record a PASS; if less than, enter FAIL in the test Form AD. It is acceptable to group the test results for several sample cans on one form following one testing setup.

Once a 277-4 sample can NCR failure has occurred verify that the setup has not shifted by rerunning the Daily Standard Setup using Form AC and calculate a new Pass Rate. If the Pass Rate has changed more then 1% than perform a new detector operation setup and NCR baseline measurements and verify the test failure rate by retesting the failed can. If the companion sample can receives two failures in a row, the associated parts shall be rejected from service, the Company Subcontract Administrator notified, and the testing continued.

A.5 Documentation of the Acceptance or Rejection Measurements

Documentation of the acceptance or rejection NCR measurements shall be made with the Forms AA through AD plus a detailed description of the active NCR measurement hardware and software that was used.

A.6 Results

A.6.1 Equipment and Software Quality Assurances

The national standard used in the PGNAA (see Section A.2) shall be provided as Certified Data.

A.6.2 Certified Tooling Setup and Repeatable Dimensions

The final tooling setup shall be manufactured and certified that the placement of the source, detector, sample can, and tooling materials are dimensional stable and repeatable to ±0.13-in.

A.6.3 Measurement Time and Repeatable Accuracy

Define the repeatable accuracy for the Nate Rate Count time selection for the production certification inspections. The Nate Rate Count time justification (see Section A.3.1.a) shall be submitted as Approval Data.

A.6.4 Measurement Software and Methodology

For the final setup the measurement software and methodolcgy method used to generate the net counts (see Section A.3.4) shall be documented and provided as Certified Data.

A.6.5 Forms AA through AD

Forms AA, AB, and AC shall be submitted as Approval Data.

After the process is approved, filled-in Forms AC and AD shall be provided as Certified Data to the Company and the casting company.

A.6.6 Can Disposition

After PGNAA testing is completed on a lot of companion sample can lot, the cans shall be returned to the Company. The PGNAA Acceptance Standards cans shall be stored for the life of the subcontract.

Casting Company Name	Certificate of Conformance of the 277-0 dry mix		
Blended Dry Batch Control Number [a]	Record the expiration date of the 277-0 dry mix [b]		
Certificate of Conformance of the B_4C dry mix	277-0 Heat Resistant Shielding Drum ID Number		
Planning	277-4 Weight	Units	Operator
Batch Size		lb	
Operation	Measurement	Units	Operator
277-0 Weight (Target = 277-4 Weight x 93.6 wt%)		lb	
B_4C Weight (Target = 277-4 Weight x 6.4 wt%)		lb	
Dry Blending Time		min.	
Comments			

[a] A 10-digit Blended Dry Batch Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

[b] Record the expiration date of the Blended Dry Batch and confirm that it is still acceptable to be cast following this specification.

FORM B 277-4 Wet Mix Control (Overcast or Special Batch) Rev F Page 1 of 1

Casting Company Name		Blended Dry Batch Control Number		
Wet Mix Control Number (WMCN) [a]		Record the expiration date of the Dry Blend Batch		
Water Temperature °F	Air Temperature °F	Measurement	Units	Operator
277-4 Weight			lb	
Water Weight (Target = 277-4 Weight × 27±1 wt%)			lb	
Mix Time			min.	
Mix Finish Time			min.	
Comments				

[a] A 10-digit Wet Mix Control Number (WMCN) shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e. 1021041515 is used for October 21, 2004 at 3:15 pm.)

Casting Company Name				Body Weldment Casting Control # [a]			
Part Serial Number				Drawing Number M2E801580A002			
Measured Weights ±0.5 lb	Casting Information			Comments		Operator	
	Weight		Date				
Clean and Empty							
Filled with Water [b]							
Water Information	Water Weight ±0.5 lb		Water Temp. [b]	Comments		Operator	
Water Conditions [b]	lb		°F				
Vibration Settings [c]	lbf		VPM				
Wet Mix Control	Blended Dry Batch Control No.			Dry Blend Batch Expiration Date			
(Target Water = 277-4 Weight × .27±1 wt%)	277-4 Weight		lb	Water Weight	lb		
	Air Temperature		°F	Water Temperature	°F		
	Mix Time			Mix Finish Time			
Companion Samples [d]	–1			–2			
	Time		Date	Comments		Operator	
Vibration Start							
Vibration Stop							
Overcast WMCN							
After Casting	lb		Date				
After Cured and Clean	lb		Date				
Measurements ⟨I⟩	Height [e] (in)	Pass or Fail Height	Cured Weight (lb)	Pass or Fail Cured Weight [e]	Cured Density [f] (lb/ft^3)	Pass or Fail 100–120 (lb/ft^3)	
Body Weldment							

[a] A 10-digit Body Weldment Casting Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests to control the companion sample castings.

[e] The acceptable cured height measurement is less than 0.25 inches. The Body Weldment cured casting weight shall be between 45.3 and 57.8 lbs.

[f] Use the above weights to calculate the density as shown below. $Density = \left(\frac{Cured - Empty}{WithWater - Empty}\right) \times 62.3$ lb/ft^3

Casting Company Name				Body Weldment Casting Control # [a]			
Part Serial Number				Drawing Number M2E801580A034			
Measured Weights ±0.5 lb	Casting Information			Comments		Operator	
	Weight		Date				
Clean and Empty							
Filled with Water [b]							
Water Information	Water Weight ±0.5 lb		Water Temp. [b]	Comments		Operator	
Water Conditions [b]	lb		°F				
Vibration Settings [c]	lbf		VPM				
Wet Mix Control	Blended Dry Batch Control No.			Dry Blend Batch Expiration Date			
(Target Water = 277-4 Weight × 27±1 wt%)	277-4 Weight		lb	Water Weight	lb		
	Air Temperature		°F	Water Temperature	°F		
	Mix Time			Mix Finish Time			
Companion Samples [d]	−1			−2			
	Time		Date	Comments		Operator	
Vibration Start							
Vibration Stop							
Overcast WMCN							
After Casting	lb		Date				
After Cured and Clean	lb		Date				
Measurements ⟨I⟩	Height [e] (in)	Pass or Fail Height	Cured Weight (lb)	Pass or Fail Cured Weight [e]	Cured Density [f] (lb/ft³)	Pass or Fail 100–120 (lb/ft³)	
Neutron Absorber Form							

[a] A 10-digit Body Weldment Casting Control Number shall be used to define the date and the time of mixing the casting batch using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Record the water weight and water temperature within 10 minutes from completion of the weighing process.

[c] Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 800 pound-force.

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests to control the companion sample castings.

[e] The acceptable cured height measurement is less than 0.25 inches. The Neutron Absorber Form cured casting weight shall be between 45.3 and 57.8 lbs.

[f] Use the above weights to calculate the density as shown below. $Density = \left(\frac{Cured - Empty}{WithWater - Empty}\right) \times 62.3 \text{ lb/ft}^3$

FORM E ES-3100 Heavy Can Spacer Assembly Lot Casting Control Rev F Page 1 of 1

Casting Company Name	Can Lot Serial Number [a]	Drawing Number M2E801580A026
Average 10 Can and Lid **Empty** Weight	Temperature of Water Weight (°F)	Average 10 Can and Lid **Water** Weight

Wet Mix Control	Blended Dry Batch Control No.		Dry Blend Batch Expiration Date	
(Target Water = 277-4 Weight × 27±1 wt%)	277-4 Weight	lb	Water Weight	lb
	Air Temperature	°F	Water Temperature	°F
	Mix Time		Mix Finish Time	
Wet Mix Control Number (Overcast), if required				

Can Serial #	After Casting Weight (lb)	Cured Weight (lb)	Pass or Fail Cured Weight [b]	Cured Height (in)	Pass or Fail Cured Height [b]	Cured Density (lb/ft^3)	Pass or Fail Cured Density [c]
Companion Samples [d]			−1				−2

Operator	Comments

[a] A 10-digit Can Lot Serial Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Heavy Can Spacer Assembly acceptable weight is 1.16 to 1.56 lbs and height 1.37±0.06 as shown in Figure 8.

[c] Use this equation for the; $Density = \left(\frac{Cured - Empty}{WithWater - Empty} \right) \times 62.3$ lb/ft^3. Acceptable 100 to 120(lb/ft^3).

[d] Use Form F, for ES-3100 Companion Sample Casting Control and Tests for Heavy Can Spacer Assembly companion samples.

Casting Company Name	Ave. 10 Can and Lid Empty Weight [a]	Ave. 10 Can and Lid Water Wgt. [a]	Temp. of Water Weight (°F)	Drawing Number M2E801580A026

Serial Numbers		Can Measurement Weights ±0.01 (lb)			For Record Only	Loss On Drying (Odd Serial Numbered Cans)		PGNAA (Even Serial Numbered Cans)	
Part # or Can Lot#	Companion Sample Can [a]	After Casting Weight	Cured Weight	LOD Weight	Cured Density (lb/ft^3)	Calculated LOD%	Pass Or Fail per Sec. 3.3.9.3	PGNAA (PMN) [c]	Pass Or Fail

Complied by	Comments

a For the same lot of sample cans, it is acceptable to use an average weight of ten can bodies and ten can lids.

b Recommended vibration settings are at 450 VPM and three times the total vibrated weight. The total vibrated weight is the finish cast part and fixtures weight, for a setting of approximately 5 pound-force.

c Record the PGNAA Measurement Number (PMN) from Form AD for each Companion Sample Can tested.

$$Density = \left(\frac{Cured - Empty}{WithWater - Empty}\right) \times 62.3 \ \text{lb/ft}^3$$

$$\text{LOD\%} = \left[1 - \frac{(LODWeight - Empty - 0.024)}{(Cured \ \& \ Clean - Empty)}\right] \times 100\%$$

Inspecting Company Name	Casting Company Name
PGNAA Tooling Setup Number [a]	277-4 Baseline Can Serial Number

Setup Distance [b]			Counts			Count Time (sec)	Net Count Rate (Net Counts/Sec)
#	Collimator	Detector	Gross	Compton	Net		

Describe the source and the amount of cadmium, lead and polyethylene surrounding the source for each Setup Number.

Describe the Software used and method to generate the net counts.

Operator

[a] A 10-digit PGNAA Tooling Setup Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm). A –# will define the setup used for testing.

[b] The 10-oz. double friction metal can lid shall face the source. The setup distances shall be measured from the can lid to the collimator face and from the can lid to the detector front face and must be documented to be repeatable to ±0.13". Also define all thickness of lead and polyethylene surrounding the source measurement to ±0.13".

[c] Use one 277-4 cast 10-oz. double friction metal can per drawing M2E801580A026 as the PGNAA reference to verify the Tooling Setup.

Inspecting Company Name				Casting Company Name			
PGNAA Standard Setup [a]				PGNAA Tooling Setup Number (with –#)			
277-4 Standard Can Serial Numbers		Counts			Count Time (sec)	Net Count Rate (Net Counts/Sec)
		Gross	Compton	Net		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Average Values						
Comments						
Operator						

a A 10-digit PGNAA Standard Setup Number shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

b The 10-oz. double friction metal can lid shall face the source following the PGNAA Standard Setup.

Inspecting Company Name	Casting Company Name
PGNAA Daily Standard Setup [a]	PGNAA Tooling Setup Number (with –#)

277-4 Standard Can Serial Numbers [b]		Counts			Count Time (sec)	Net Count Rate (Net Counts/Sec)
		Gross	Compton	Net		
1						
2						
3						
4						
5						
Average Values						
Standard Deviation						
3 × Standard Deviation						
(Pass Rate) Minimum Acceptable Net Count Rate = Average – 3 × Standard Deviation =						

Comments
Operator

[a] A 10-digit PGNAA Daily Standard Setup (DSS) shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

[b] Select five PGNAA acceptance standards from Form AB as the Daily Standard Setup that generate approximately the same average and standard deviation as on Form AB.

FORM AD PGNAA Measurements **Rev F Page 1 of 1**

Inspecting Company Name	Casting Company Name

PGNAA Measurement Number (PMN) [a]	PGNAA Daily Standard Setup Num.	PGNAA Pass Rate (Net Cnt/Sec)

Even Serial Numbers [b]		Counts (Cnt)			Count Time (sec)	Net Cnt Rate (NetCnt/Sec)	Pass or Fail
Drum/Neutron Absorber Form/Lot#	Sample #	Gross	Compton	Net			

Comments
Operator

a A 10-digit PGNAA Measurement Number (PMN) shall be used to define the date and the time of setup using the format with a 24-hour clock (i.e., 1021041515 is used for October 21, 2004 at 3:15 pm).

b Record the Body Weldment, Neutron Absorber Form, or Heavy Can Spacer Assembly can lot with the Companion Sample Number.

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-1	Revision F
	Issue Date 2/17/2005	Revision Date 10/12/2006
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	OFFER APPRAISAL DATA - Subcontractor				
	The Offerer shall submit the following data with the offer.				
1	Subcontractor's quality assurance program manual	4.1	1	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify) Specimen

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-2		Revision F
	Issue Date 2/17/2005	Revision Date 10/12/2006	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	APPROVAL DATA - Subcontractor				
	The Subcontractor shall provide the following data prior to the start of production casting.				
1	Process equipment approval	3.1	1	E	
2	Scale Certifications	3.2.1	1	E	
3	Request for Company approved equal	3.2.2, 3.2.6, 3.2.7, 6.4	1	E	
4	MSDS for cleaning products	3.4.1	1	E	
5	Procedures	4.2.4	1	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-3	Revision F
	Issue Date 2/17/2005	Revision Date 10/12/2006
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	CERTIFIED DATA - Subcontractor				
	Item 1 shall be provided prior to the start of production casting.				
1	Approved procedures	4.2.4	1	E	
	Item 2 shall be provided with each ES-3100 unit.				
2	ES-3100 Documentation Package	4.2.1	1	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-4		Revision F
	Issue Date 2/17/2005	Revision Date 10/12/2006	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	OFFER APPRAISAL DATA – PGNAA Subcontractor				
	The Offerer shall submit the following data with the offer.				
1	Subcontractor's quality assurance program manual	4.1	1	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify) Specimen

EQUIPMENT SPECIFICATION	**Specification Number** JS-YMN3-801580-A005-5		**Revision** F
	Issue Date 2/17/2005	**Revision Date** 10/12/2006	
		Page 1 of 1	

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	APPROVAL DATA – PGNAA Subcontractor				
	The Subcontractor shall provide the following data prior to the start of production inspection.				
1	Source, detector, and software must be certified to a national standard.	A.6.1	1	E	
2	Final tooling setup shall be manufactured - Results of final tooling setup dimensional inspection shall be provided showing repeatability to +/- 0.13" - As built drawing of final tooling setup that was manufactured shall be provided showing setup distances and materials of construction	A.6.2	1	E	
3	Results of Net Count Rate Measurements performed on manufactured final tooling setup per section A.3.1.a of specification, based upon at least a 20 hour PGNAA measurement count and time justification.	A.6.3	1	E	
4	Software used to determine net count rate and methodology used to determine net count rate shall be identified and documented	A.6.4	1	E	
5	Completed Forms AA	A.6.5	1	E	
6	Completed Forms AB, and AC	A.6.5	1	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

# EQUIPMENT SPECIFICATION	Specification Number JS-YMN3-801580-A005-6	Revision F
	Issue Date 2/17/2005	Revision Date 10/12/2006
		Page 1 of 1

MANUFACTURER'S DATA REQUIREMENTS

Item No.	Data Submittal—Purpose and Description	Specification or Reference	Number of Copies	Form[a]	
	CERTIFIED DATA - PGNAA Subcontractor				
	Item 1 and 2 shall be provided prior to the start of production PGNAA inspection.				
1	PGNAA national standard	A.6.1	1	E	
2	PGNAA measurement software and methodology	A.6.4	1	E	
	Item 3 shall be provided after each companion can lot is inspected.				
3	Forms AC and AD	A.6.5	2 (1 copy going to Casting Company)	E	

[a]Indicate the following:

A—Full-size prints
B—Full-size reproducibles
C—Microfilm aperture card
D—Manual (booklet, brochure, report, etc.)
E—Other (Specify) Subcontractor's standard form
F—Other (Specify)
S—Sample of Workmanship

APPENDIX 1.4.6

PACKAGE CATEGORY DETERMINATION

PACKAGE CATEGORY DETERMINATION

The ES-3100 with HEU content package has a maximum activity of 0.3243 Tbq (8.76 Ci) at 10 y after initial fabrication; the maximum number of A_2s carried is 294.00 at 70 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.

APPENDIX 1.4.7

HEU OXIDE MATERIAL SPECIFICATION AS PROVIDED BY Y-12 HIGHLY ENRICHED URANIUM DISPOSITION PROGRAM OFFICE

Uranium oxide material limits

Specified item	Units	Limit	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Chemical form [a]			UO_x	UO_x	UO_x	U_3O_8	UO_x	UO_x	U_3O_8
Physical form			Dense, loose powder, may contain lumps						
Uranium content									
Uranium purity	gU/gSmpl	≥	0.830	0.200	0.830	0.830	0.200	0.200	0.845
U-235	g/gU	≤	97.7%	97.7%	97.7%	97.7%	97.7%	97.7%	93.2%
U-238	g/gU	≤	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
U-232	μg/gU	≤	0.040	0.040	0.040	0.040	0.040	0.040	0.040
U-233	μg/gU	≤	50	50	50	50	50	200	50
U-234	g/gU	≤	1.4%	1.4%	1.4%	1.4%	1.4%	2.0%	1.4%
U-236	g/gU	≤	1.0%	1.0%	1.0%	1.0%	1.0%	40.0%	1.0%
Transuranics (Np, Pu, Am, etc.)									
Concentration limit	μg/gU	≤	0.2	0.2	40.0	0.2	0.5	0.5	0.2
Activity limit	Bq/gU	≤	50	50	600,000	3,000	5,000	1,000	3,000
Unspecified beta emitters									
Activity limit	Bq/gU	≤	200	200	200	200	1,000,000[c]	10,000	200
Moisture	g/gSmpl	≤	6%	6%	6%	6%	6%	6%	6%
Carbon	μg/gU	≤	600	1,000	600	600	1,000	1,000	171,000
EBC [b]	μgEBC/gU	≤	4	10,000	4	4	10,000	10,000	4

[a] UO_x may be UO_2 or UO_3.
[b] EBC = equivalent boron content, as defined in ASTM standard C1233-98.
[c] The oxide contents of the ES-3100 were characterized with the beta emitters as an "unspecified" feature in order to establish one group limit for these nuclides rather than limits on each (of many) individual nuclides. The beta emitters are either daughter products from the decay of uranium isotopes, or activation and fission products from reprocessed material. The beta nuclides most often seen in this material are Tc-99, Sr-90, and Cs-137. Table 1.4.7-1 gives a complete list of the beta-emitting nuclides that have been observed in various oxides intended for shipment in the ES-3100. The maximum mass concentration allowable by the 1,000,000 Bq/gU activity limit is for Group 5 oxides.

Table 1.4.7-1

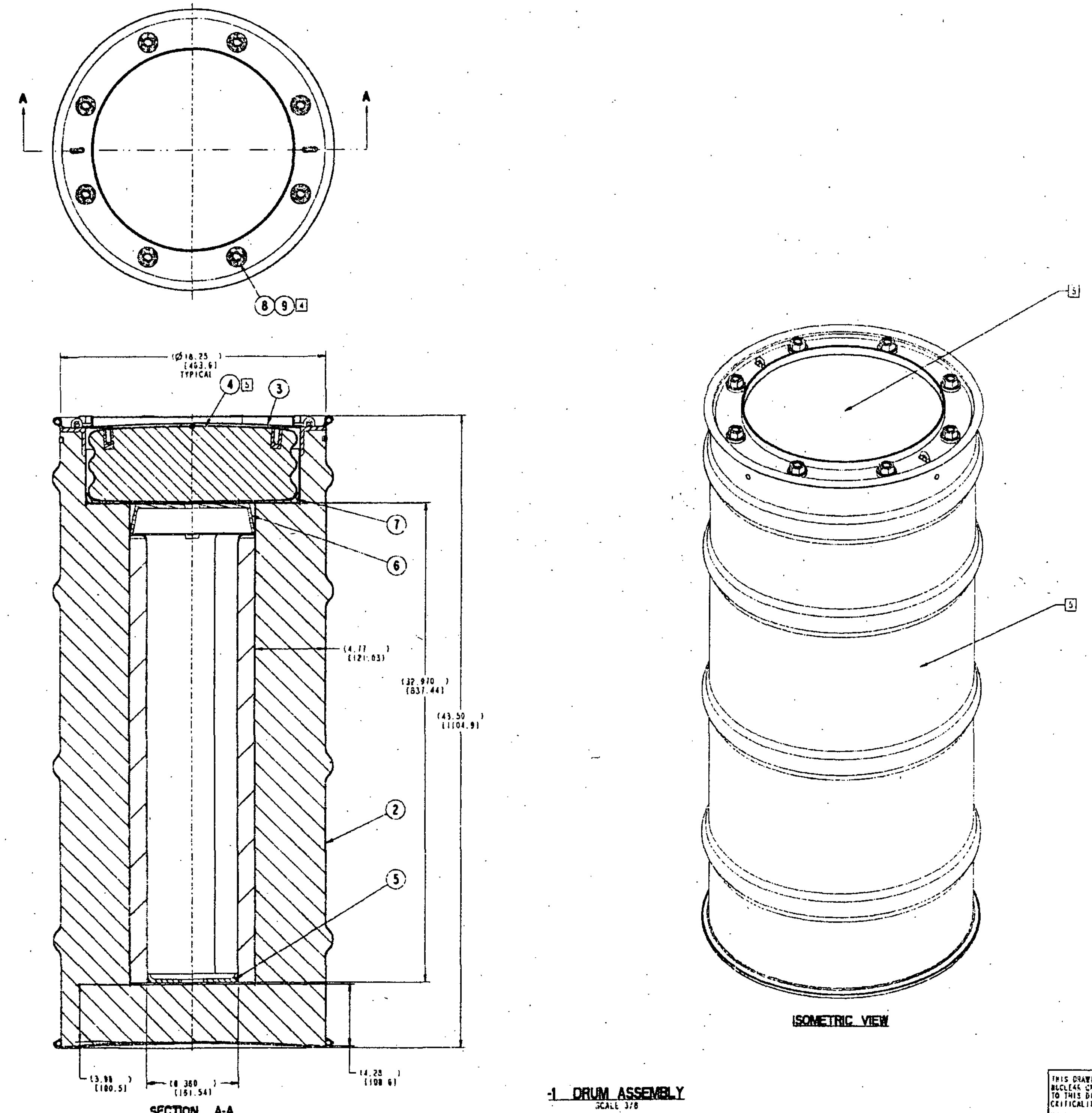
Radionuclide Reference Data - Beta Nuclides

Isotope				Specific Activity Calculation			Rad	Mass Conc
Element	Sym	At #	Iso	Mass	T½, Yr	SA, Bq/g	Type	at 10^6 Bq/gU µg/gU
Cobalt	Co	27	58	57.935755	0.194	1.177E+15	ß+	8.500E-04
Cobalt	Co	27	60	59.933819	5.271	4.187E+13	ß-	0.024
Strontium	Sr	38	90	89.907738	29.100	5.056E+12	ß-	0.198
Zirconium	Zr	40	95	94.908042	0.175	7.951E+14	ß-	0.001
Niobium	Nb	41	95	94.906835	0.096	1.456E+15	ß-	6.870E-04
Technetium	Tc	43	99	98.906254	2.130E+05	6.279E+08	ß-	1,592.656
Ruthenium	Ru	44	103	102.906323	0.108	1.196E+15	ß-	8.365E-04
Ruthenium	Ru	44	106	105.907321	1.020	1.224E+14	ß-	0.008
Antimony	Sb	51	125	124.905252	2.758	3.840E+13	ß-	0.026
Cesium	Cs	55	134	133.906696	2.065	4.784E+13	ß-	0.021
Cesium	Cs	55	137	136.907073	30.300	3.189E+12	ß-	0.314
Cerium	Ce	58	141	140.908271	0.089	1.055E+15	ß-	9.479E-04
Cerium	Ce	58	144	143.913643	0.779	1.180E+14	ß-	0.008
Europium	Eu	63	155	154.922889	4.710	1.813E+13	ß-	0.055
Thallium	Tl	81	208	207.981988	5.805E-06	1.096E+19	ß-	9.127E-08
Thallium	Tl	81	209	208.985334	4.183E-06	1.513E+19	ß-	6.609E-08
Lead	Pb	82	209	208.981065	3.708E-04	1.707E+17	ß-	5.858E-06
Lead	Pb	82	210	209.984163	22.600	2.787E+12	ß-	0.359
Lead	Pb	82	211	210.988735	6.864E-05	9.134E+17	ß-	1.095E-06
Lead	Pb	82	212	211.991871	0.001	5.141E+16	ß-	1.945E-05
Lead	Pb	82	214	213.999798	5.134E-05	1.204E+18	ß-	8.305E-07
Bismuth	Bi	83	210	209.984095	0.014	4.592E+15	ß-	2.178E-04
Bismuth	Bi	83	211	210.987255	4.069E-06	1.541E+19	ß-,a	6.490E-08
Bismuth	Bi	83	212	211.991255	1.151E-04	5.421E+17	ß-,a	1.845E-06
Bismuth	Bi	83	213	212.994359	8.670E-05	7.163E+17	ß-,a	1.396E-06
Bismuth	Bi	83	214	213.998691	3.784E-05	1.634E+18	ß-	6.121E-07
Thorium	Th	90	231	231.036298	0.003	1.967E+16	ß-	5.083E-05
Thorium	Th	90	234	234.043593	0.066	8.565E+14	ß-	0.001
Protactinium	Pa	91	234m	234.043303	2.225E-06	2.541E+19	ß-	3.936E-08

APPENDIX 1.4.8

DETAILED ENGINEERING DRAWINGS

Drawing No.	Rev.	Title
M2E801580A001	B	Drum Assembly
M2E801580A002	B	Body Weldment
M2E801580A003	B	Inner Liner Weldment (2 sheets)
M2E801580A004	B	Double Open Head Reinforced Drum
M2E801580A005	B	Misc. Details
M2E801580A006	B	Drum Lid Weldment
M2E801580A007	B	18.25" Diameter Drum Lid
M2E801580A008	B	Top Plug Weldment
M2E801580A009	C	Pad Details
M2E801580A010	C	Data Plate Details
M2E801580A011	C	Containment Vessel Assembly
M2E801580A012	C	Containment Vessel Body Assembly (2 sheets)
M2E801580A013	B	Containment Vessel O-ring Details
M2E801580A014	B	Containment Vessel Lid Assembly
M2E801580A015	C	Containment Vessel Sealing Lid
M2E801580A016	B	Containment Vessel Closure Nut
M2E801580A026	C	Heavy Can Spacer Assembly
M2E801580A031	C	Main Assembly



-1 DRUM ASSEMBLY
SCALE 3/8

NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm]. THE [mm] ARE ONLY FOR REFERENCE.
4. TORQUE HEX NUTS TO 30±5 ft-lb AT ASSEMBLY.
5. IN APPROXIMATE LOCATIONS SHOWN, USING BLACK ENAMEL PAINT (F/N 10), PAINT DRAWING NUMBER, REVISION LETTER AND FIVE DIGIT SERIAL NUMBER IN 1.00" HIGH CHARACTERS ON F/N 2, F/N 3, AND F/N 4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002
7. FOR REF. ONLY APPROXIMATE WEIGHT: 289.2 LBS [131.2 Kg].

QTY REQ'D	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
AR		PAINT, BLACK ENAMEL		FED SPEC 5958-17038	10
8	M2E801580A005-3	DRUM HEX NUT			9
8	M2E801580A005-4	DRUM WASHER			8
1	M2E801580A039-3	PLUG PAD			7
1	M2E801580A009-2	CV FLANGE PAD			6
1	M2E801580A009-1	CV BOTTOM PAD			5
1	M2E801580A008-1	TOP PLUG WELDMENT			4
1	M2E801580A006-1	DRUM LID WELDMENT			3
1	M2E801580A002-1	BODY WELDMENT			2
AR	-1	DRUM ASSEMBLY			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date: 2/10/05

REV	DESCRIPTION	DRN	CHKR	DE	DVR	PM	DATE	PE	DATE	PR	DATE
B	GEN REV: TORQUE IN NOTE 4 WAS 10 +/- 1. REVISED NOTES 4 & 7; F/N 8 & 9 WAS VENDOR SUPPLIED. MOVED NUT & WASHER DETAILS TO A005.	JRP	GMM	GAB	RDA	DPS		GAB		JGA	
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW		MRF		DHM	

REVISION OR ISSUE PURPOSE

P THIS DRAWING PRODUCED OR PRO/ENGINEER

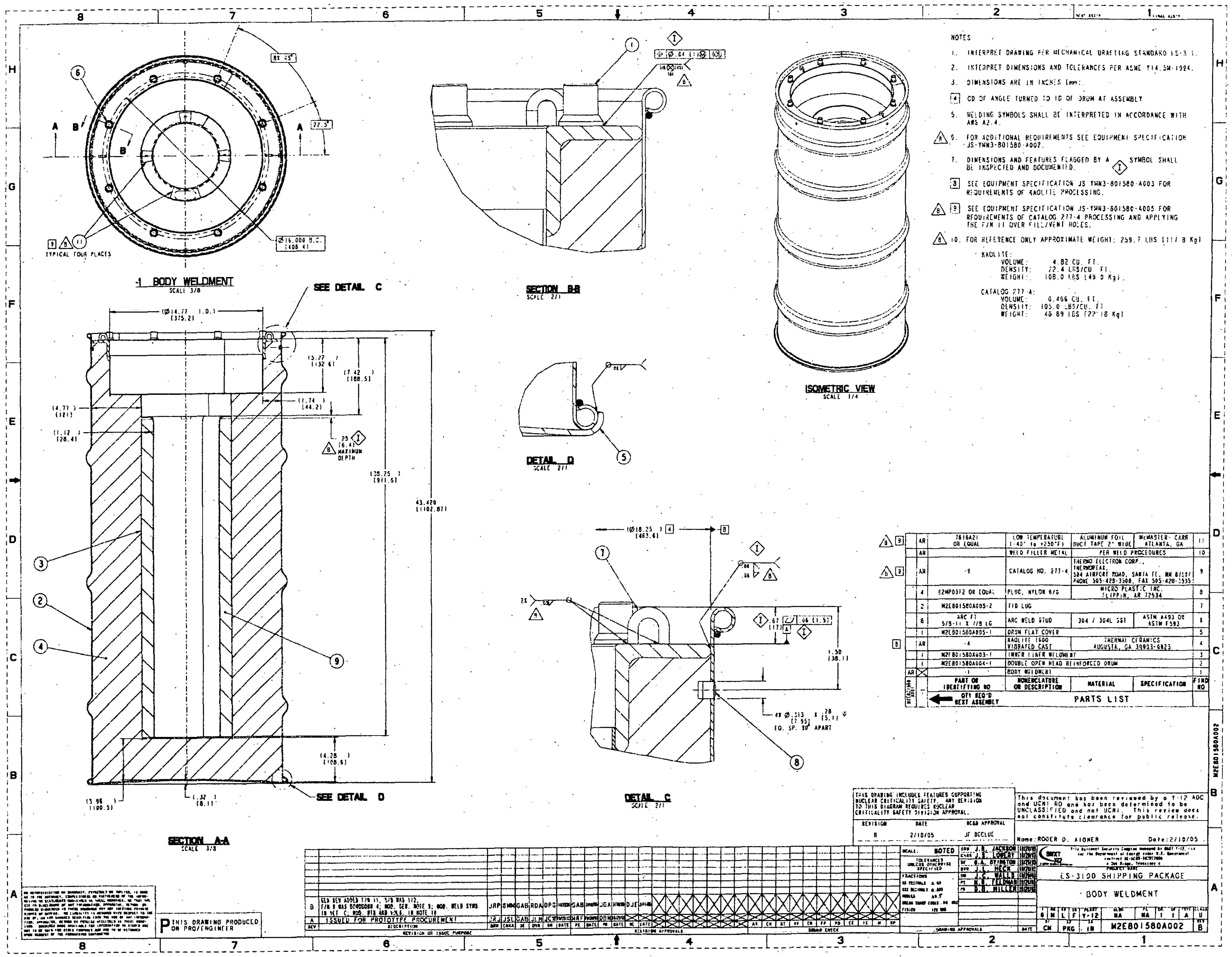
SCALE: NOTED

DRAWING APPROVALS	
DRN	JR JACKSON
CHKR	JS LOWERY
DE	GA BYINGTON
DVR	JL HECK
DM	JC WALLS
PE	MR FELDMAN
PM	DH MILLER

ES-3100 SHIPPING PACKAGE

DRUM ASSEMBLY

PLANT Y-12 — M2E801580A001 — REV B



NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES [mm].
4. OD OF ANGLE TURNED TO ID OF DRUM AT ASSEMBLY
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
7. DIMENSIONS AND FEATURES FLAGGED BY A ⟨I⟩ SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A003 FOR REQUIREMENTS OF KAOLITE PROCESSING.
9. SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A005 FOR REQUIREMENTS OF CATALOG 277-4 PROCESSING AND APPLYING THE F/N 11 OVER FILL/VENT HOLES.
10. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 259.7 LBS [117 8 Kg]

KAOLITE:
VOLUME: 4.82 CU. FT.
DENSITY: 22.4 LBS/CU. FT.
WEIGHT: 108.0 LBS [49 0 Kg].

CATALOG 277-4:
VOLUME: 0.466 CU. FT.
DENSITY: 105.0 LBS/CU. FT
WEIGHT: 48 89 LBS [22 18 Kg]

	QTY REQ'D	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR	7616A21 OR EQUAL	LOW TEMPERATURE (-40° to +250°F)	ALUMINUM FOIL DUCT TAPE 2" WIDE	McMASTER-CARR ATLANTA, GA	11
	AR		WELD FILLER METAL	PER WELD PROCEDURES		10
	AR	-9	CATALOG NO. 277-4	THERMO ELECTRON CORP., THERMOPEAK, 584 AIRPORT ROAD, SANTA FE, NM 87507 PHONE 505-428-3508, FAX 505-428-3535		9
	4	82MP0312 OR EQUAL	PLUG, NYLON 6/6	MICRO PLASTIC INC. FLIPPIN, AR 72534		8
	2	M2E801580A005-2	TID LUG			7
	6	ARC FT 5/8-11 X 7/8 LG	ARC WELD STUD	304 / 304L SST	ASTM A493 OR ASTM F593	6
	1	M2E801580A005-1	DRUM FLAT COVER			5
	AR	-4	KAOLITE 1600 VIBRATED CAST	THERMAL CERAMICS AUGUSTA, GA 30903-0923		4
	1	M2E801580A003-1	INNER LINER WELDMENT			3
	1	M2E801580A004-1	DOUBLE OPEN HEAD REINFORCED DRUM			2
AR		-1	BODY WELDMENT			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date: 2/10/05

B — FLD REV ADDED F/N 11, 5/8 WAS 1/2, F/N 8 WAS 82MP0312 4; MOD. GEN. NOTE 9; MOD. WELD SYMS IN VET C. MOD. WTS AND VOLS. IN NOTE 10

A — ISSUED FOR PROTOTYPE PROCUREMENT

THIS DRAWING PRODUCED ON PRO/ENGINEER

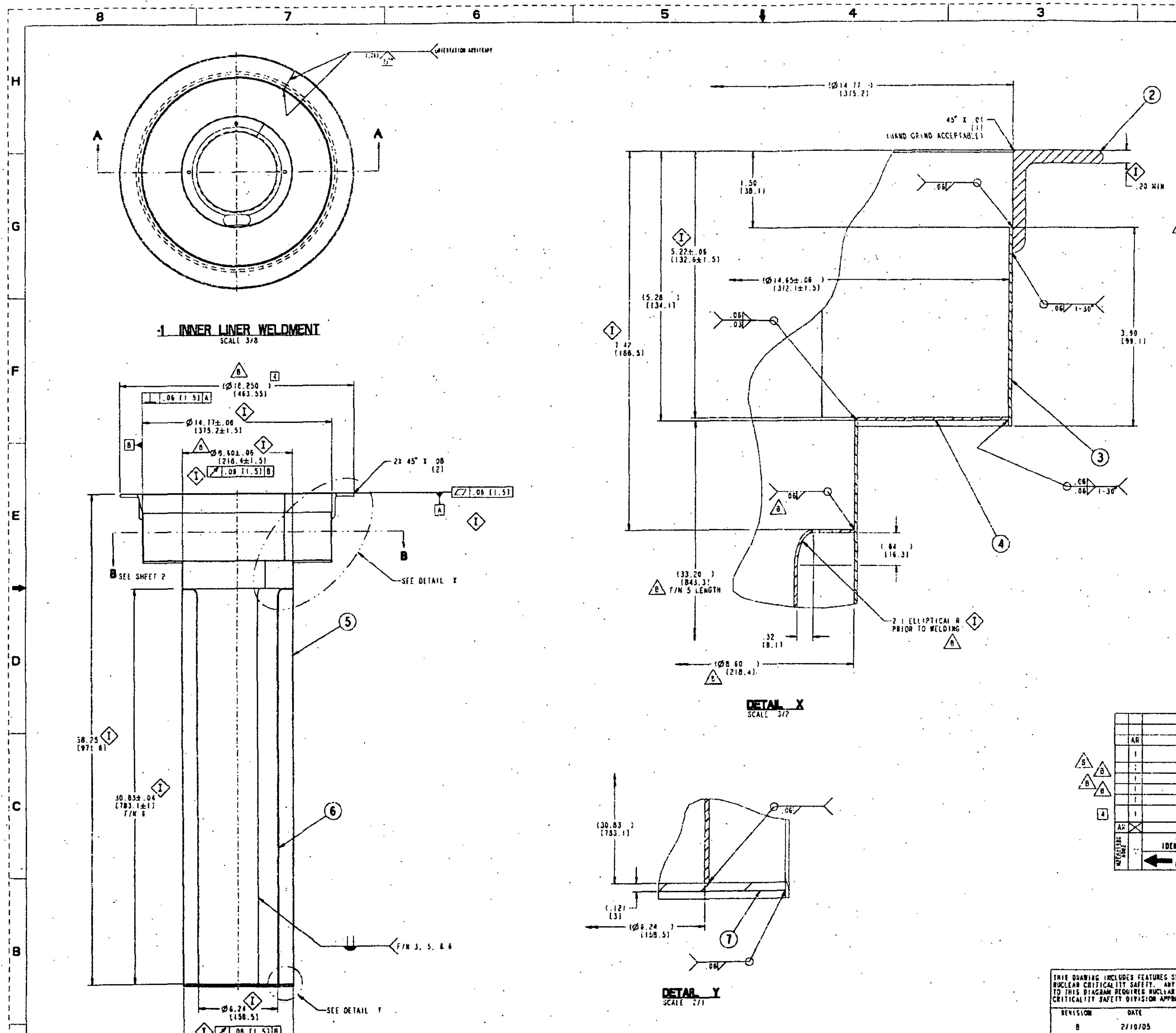
SCALE: NOTED

DRN J.R. JACKSON; CHKD J.S. LOWERY; DE G.A. BYINGTON; DVR J.L. HECK; DM J.C. WALLS; PE M.R. FELDMAN; PM D.B. MILLER

ES-3100 SHIPPING PACKAGE

BODY WELDMENT

M2E801580A002 REV B



NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES 3.1
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES (mm).
4. FINAL DIAMETER SET BY DRUM INSIDE DIAMETER. +.01 TO -.06 TOLERANCE
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
7. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

	QTY REQ'D	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR		WELD FILLER METAL			8
	1	-7	BOTTOM PLATE	11 GAGE SHEET 304/304L SST	ASME SA240	7
	1	-6	LOWER INNER RING	16 GAGE SHEET 304/304L SST	ASME SA240	6
	1	-5	LOWER OUTER RING	16 GAGE SHEET 304/304L SST	ASME SA240	5
	1	-4	UPPER FLOOR PLATE	16 GAGE SHEET 304/304L SST	ASME SA240	4
	1	-3	UPPER OUTER RING	16 GAGE SHEET 304/304L SST	ASME SA240	3
	1	2	2 X 2 X 1/4 ANGLE MODIFIED	304/304L SST	ASME SA479	2
AR		-1	INNER LINER WELDMENT			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

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Name: ROGER D. AIGNER Date: 2/10/05

REV	DESCRIPTION
B	DELETED F/N 7. RENUMBERED F/N 8 TO 7 AND F/N 9 TO 8. CHANGED F/N 5 Ø8.80 TO Ø8.60. LENGTH 2.14 TO 33.20. F/N 6 OD WAS Ø9.13 NOW Ø8.60. REMOVED NOTE 8
A	ISSUED FOR PROTOTYPE PROCUREMENT

SCALE: NOTED

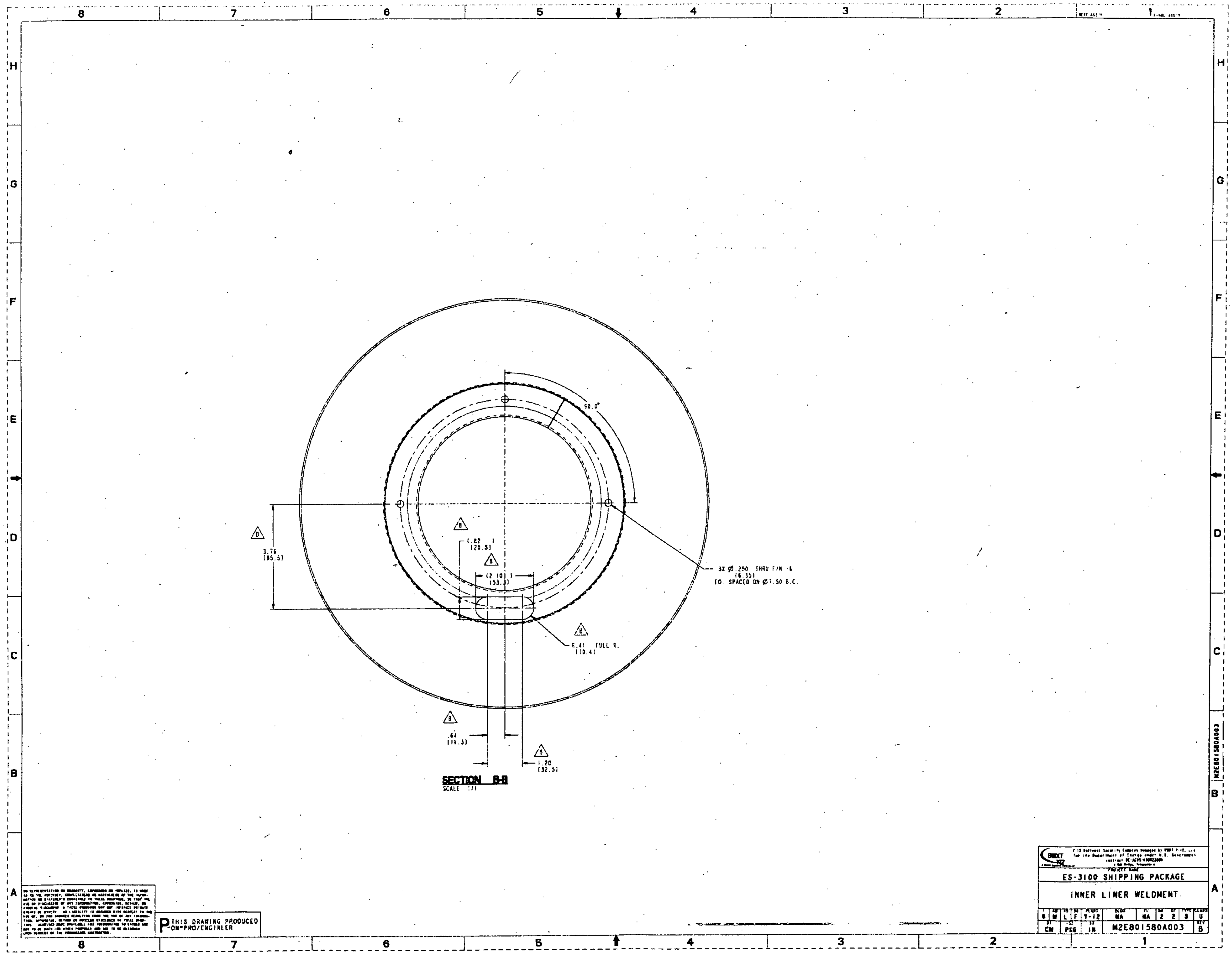
DWG J.R. JACKSON; CHKR J.S. LOWERY; DE G.A. BYINGTON; DVR J.L. HECK; DM J.C. WALLS; PE N.R. FELDMAN; PM D.B. MILLER

ES-3100 SHIPPING PACKAGE

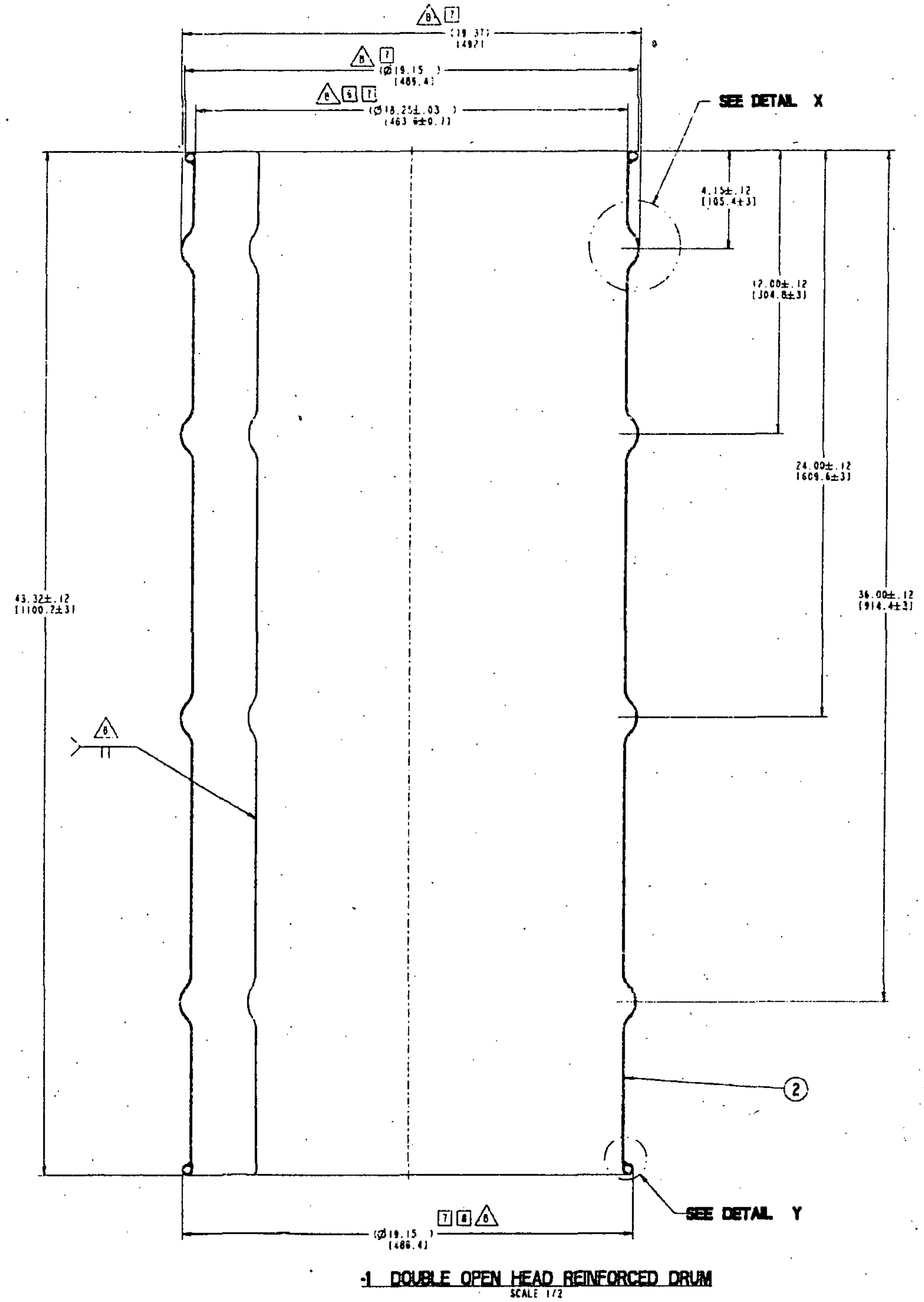
INNER LINER WELDMENT

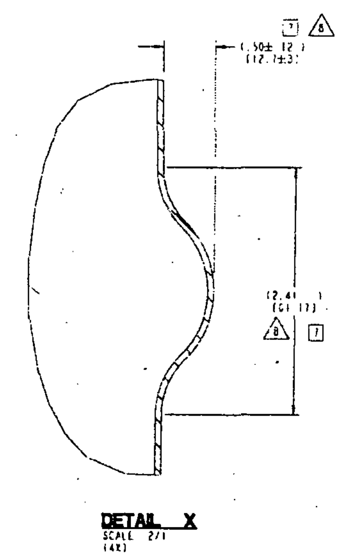
M2E801580A003 REV B

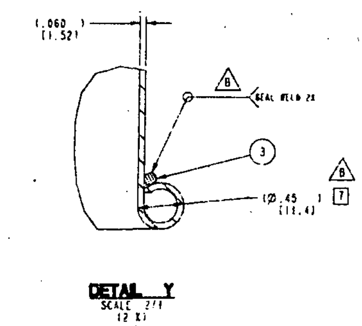
P THIS DRAWING PRODUCED ON PRO/ENGINEER

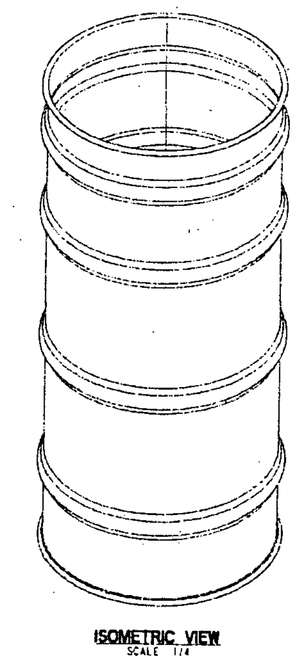


90.0°
3.76
[95.5]
(.82)
[20.8]
(2.10)
[53.3]
3X Ø.250 THRU F/N -6
[6.35]
EQ. SPACED ON Ø7.50 B.C.
R.41 FULL R.
[10.4]
.64
[16.3]
1.28
[32.5]
SECTION B-B
SCALE 1/1
THIS DRAWING PRODUCED ON PRO/ENGINEER
ES-3100 SHIPPING PACKAGE
INNER LINER WELDMENT
T-12
M2E801580A003









NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994
3. DIMENSIONS ARE IN INCHES.[mm].
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. (B) FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS YMN3-801580-A002
6. (B) INSPECT THE I.D. OF THE DRUM TO DETERMINE THE ACTUAL DIAMETER DIMENSION FOR FABRICATION INTERFACE WITH M2E801580A003. REFERENCE NOTE 4 ON DWG. M2E801580A002.
7. (B) DRUM DIAMETERS, CORRUGATIONS, AND MANUFACTURING SHALL MEET THE REQUIREMENTS OF MILITARY STANDARD, MS27683-7 (DRUM, METAL SHIPPING AND STORAGE (6 TO 80 GALLS)). THE SEAM WELD OF THE DOUBLE OPEN-HEAD DRUM SHALL BE TESTED BY APPLYING AN EXTERNAL AIR PRESSURE TO 10 PSIG (MIL-D-6054F, PARAGRAPH 4.6.1 PROCEDURE B) AND BY CONDUCTING A ROUGH HANDLING TEST (MIL-D-6054F, PARAGRAPH 4.5.2)
8. (B) INSPECT THE O.D. OF THE DRUM FOR INTERFACE DIMENSION WITH M2E801580A005-1, DRUM FLAT COVER. REFERENCE NOTE 5 ON DRAWING M2E801580A005.

	AR		WELD FILLER METAL	PER WELD PROCEDURES		4
	AR	Ø1/8	WELD WIRE	ER308L	ASME SFA 5.9	3
	1	-2	DRUM 16 GA (.0595)	304/304L SST	ASME SA240	2
AR	X	-1	DOUBLE OPEN HEAD REINFORCED DRUM			1
	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
QTY REQ'D NEXT ASSEMBLY			PARTS LIST			

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/15/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date: 2/10/05

REV	DESCRIPTION	DRN	CHKR
B	GEN REV REMOVED TOL ON 18.25 DIA. REMOVED (I) ON 19.15 DIA. REMOVED BOX 9 DIM. UPDATED NOTE NUM. 6 TO 8. REVISED NOTE 7. MOD. WELD SYMBOLS. ADDED REF DIMENSIONS IN DETAIL X	JRP	SMO
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL

REVISION OR ISSUE PURPOSE

THIS DRAWING PRODUCED ON PRO/ENGINEER

SCALE: NOTED

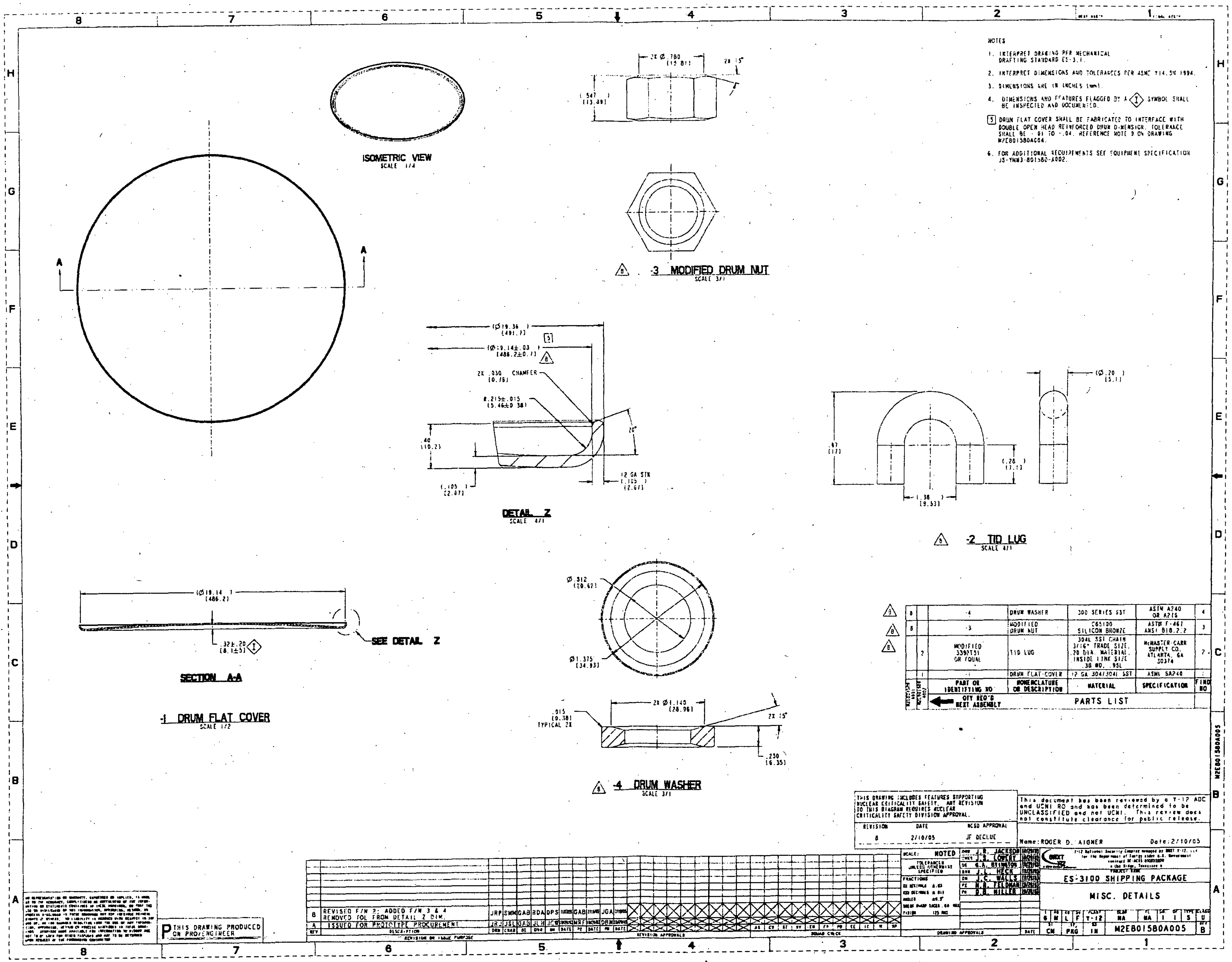
DRN J.R. JACKSON; CHKR J.S. LOWERY; EK G.A. BYINGTON; DVR J.L. HECK; OM J.C. WALLS; PE N.K. FELDMAN; PE D.D. MILLER

DRAWING APPROVALS

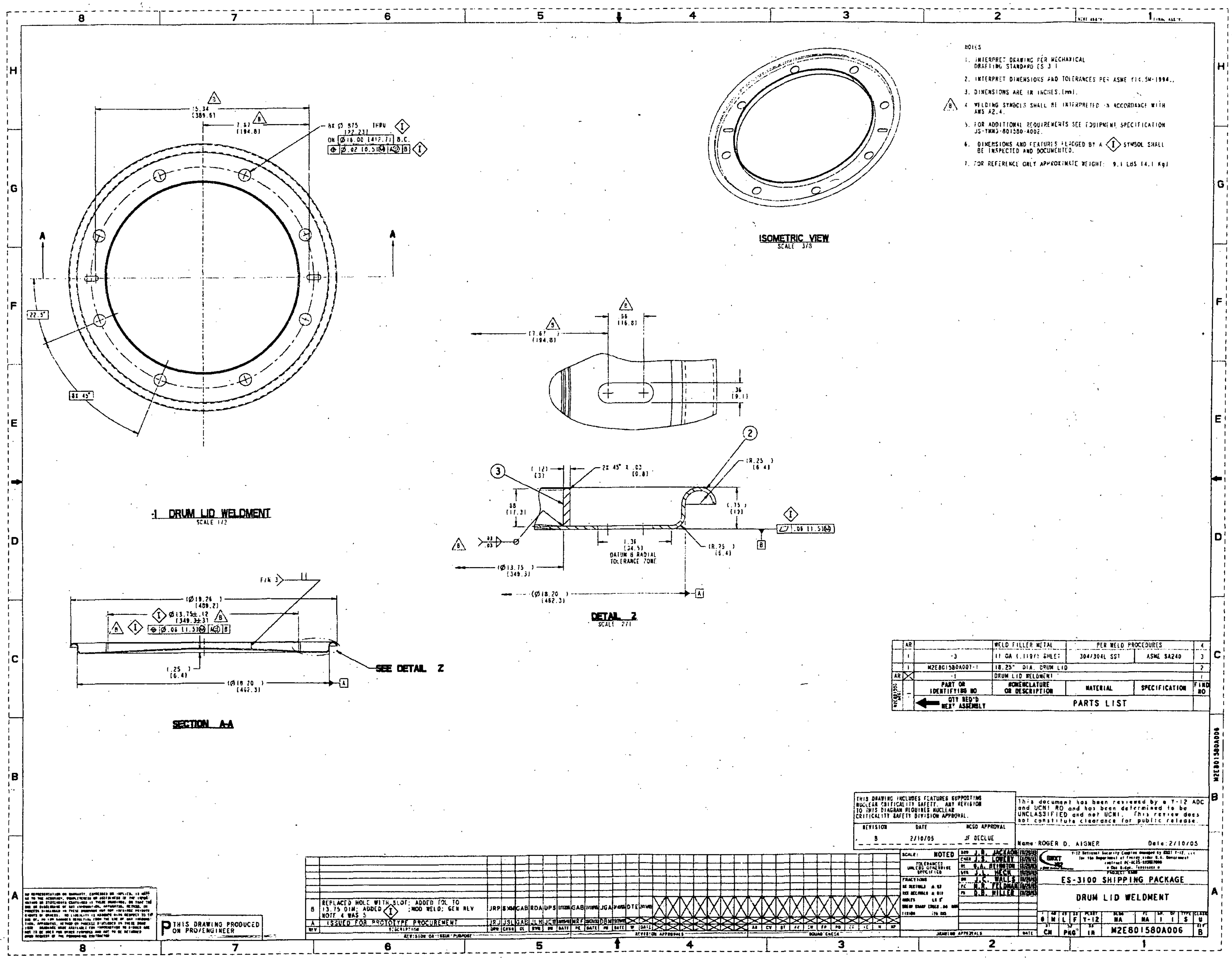
PROJECT NAME: ES-3100 SHIPPING PACKAGE

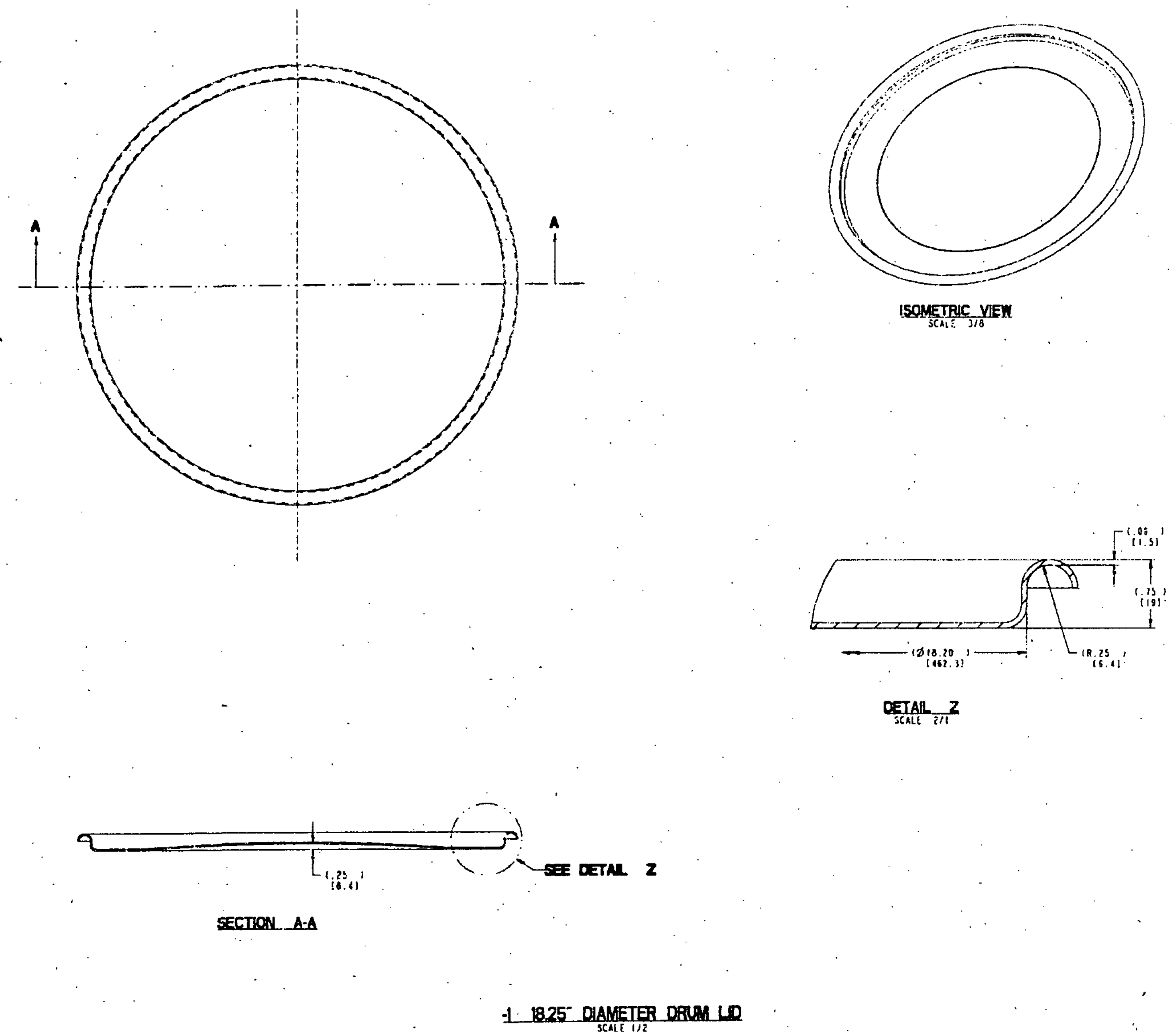
DOUBLE OPEN HEAD REINFORCED DRUM

6	M	L	F	Y-12	NA	NA	1	1	S	U
CM	PKG	-IN	M2E801580A004							B



		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
8		-4	DRUM WASHER	300 SERIES SST	ASTM A240 OR A276	4
8		-3	MODIFIED DRUM NUT	C65100 SILICON BRONZE	ASTM F-467 ANSI B18.2.2	3
	2	MODIFIED 3392T51 OR EQUAL	TID LUG	304L SST CHAIN 3/16" TRADE SIZE, .20 DIA. MATERIAL, INSIDE LINK SIZE .38 WD, .95L	McMASTER-CARR SUPPLY CO. ATLANTA, GA 30374	2
	1	-1	DRUM FLAT COVER	12 GA 304/304L SST	ASME SA240	1


-1 DRUM LID WELDMENT
SCALE 1/2
ISOMETRIC VIEW
SCALE 3/8
DETAIL Z
SCALE 2/1
SECTION A-A
SEE DETAIL Z
NOTES
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES 3 1
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.[mm].
4. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. DIMENSIONS AND FEATURES FLAGGED BY A (I) SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
7. FOR REFERENCE ONLY APPROXIMATE WEIGHT: 9.1 LBS [4.1 Kg]
AR | | WELD FILLER METAL | PER WELD PROCEDURES | 4
1 | -3 | 11 GA (.1197) SHEET | 304/304L SST | ASME SA240 | 3
1 | M2E801580A007-1 | 18.25" DIA. DRUM LID | 2
AR | -1 | DRUM LID WELDMENT | 1
PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO
QTY REQ'D NEXT ASSEMBLY
PARTS LIST
THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.
REVISION | DATE | NCSD APPROVAL
B | 2/10/05 | JF DECLUE
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name: ROGER D. AIGNER
Date: 2/10/05
SCALE: NOTED
J.R. JACKSON
J.S. LOWERY
G.A. BYINGTON
J.L. HECK
J.C. WALLS
M.R. FELDMAN
D.B. MILLER
ES-3100 SHIPPING PACKAGE
DRUM LID WELDMENT
Y-12
M2E801580A006
B
ISSUED FOR PROTOTYPE PROCUREMENT
THIS DRAWING PRODUCED ON PRO/ENGINEER



NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.(mm).
4. FOR ADDITIONAL INFORMATION SEE EQUIPMENT SPECIFICATION DS-YMN3-801580A002.
5. LID SHALL BE FABRICATED IN ACCORDANCE WITH MILITARY SPECIFICATION MS27683-61, COVER STYLE 1.

AR	-1	18.25" DIA. DRUM LID	16 GA 304/304L SST	ASME SA240	1
QTY REQ'D NEXT ASSEMBLY	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
		PARTS LIST			

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

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Name: ROGER D. AIGNER Date 2/10/05

REV	DESCRIPTION
B	GENERAL REVISION
A	ISSUED FOR PROTOTYPE PROCUREMENT

SCALE: NOTED

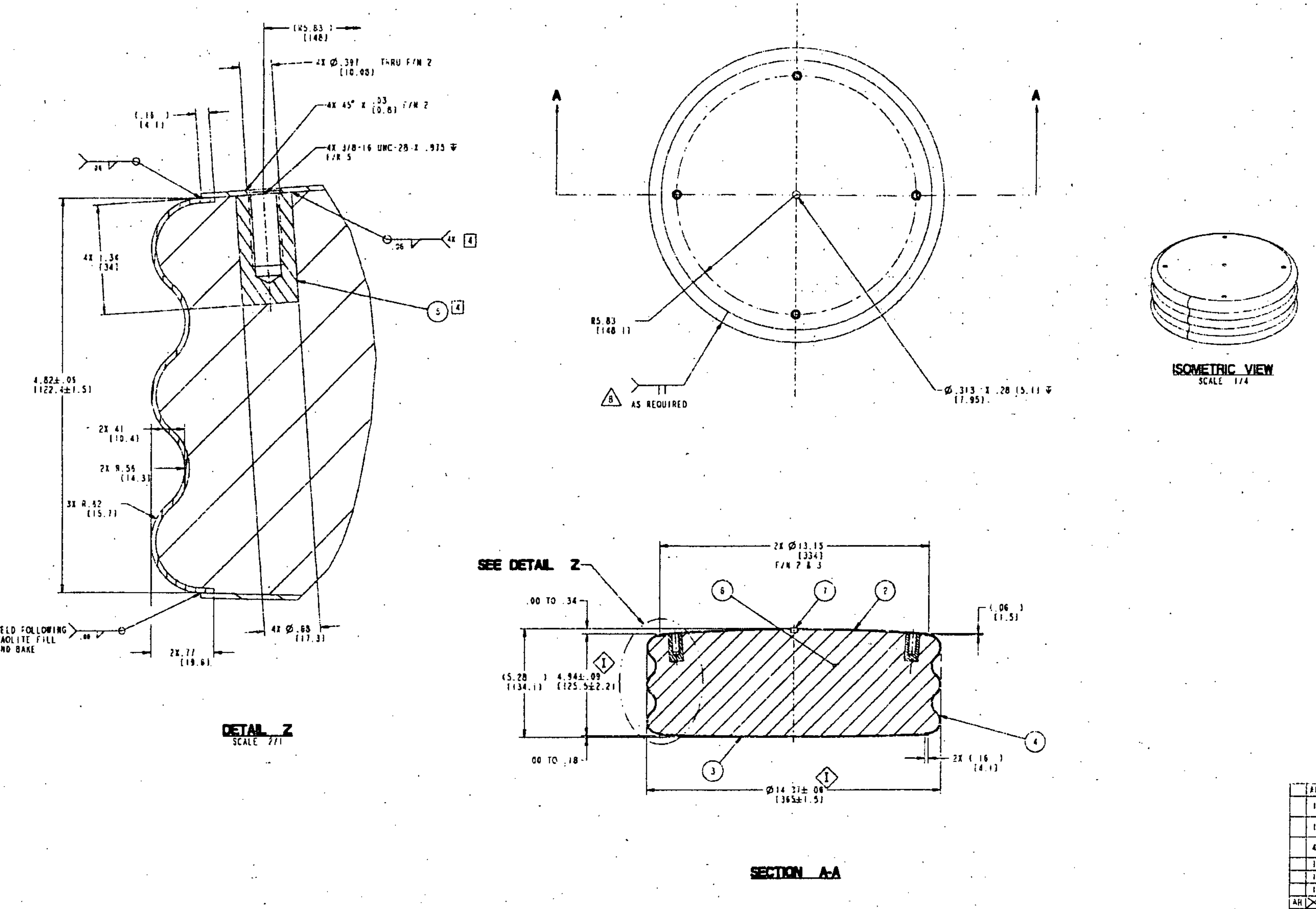
DRN J.R. JACKSON; CHKR J.S. LOWERY; GE G.A. BYINGTON; DTR J.L. HECK; DM J.C. WALLS; PE H.R. FELDMAN; PM O.B. MILLER

ES-3100 SHIPPING PACKAGE

18.25" DIAMETER DRUM LID

M2E801580A007 REV B

P THIS DRAWING PRODUCED ON PRO/ENGINEER



-1 TOP PLUG WELDMENT
SCALE 1/2

NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994
3. DIMENSIONS ARE IN INCHES.[mm].
4. (boxed) WELD LIFTING INSERTS (F/N 5) IN PLACE BEFORE FILLING WITH KAOLITE (F/N 6).
5. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATIONS JS-YMN3-801580-A002 AND A003.
7. DIMENSIONS AND FEATURES FLAGGED BY A ⟨I⟩ SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
8. FOR REFERENCE ONLY:
APPROXIMATE WEIGHT 19.6 LBS [8.9 Kg] WITH
KAOLITE VOLUME 0.43 CU.FT.
KAOLITE DENSITY 22.4 LBS/CU. FT.
KAOLITE WEIGHT: 9.6 LBS [4.7 Kg]

QTY REQ'D		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR		WELD FILLER METAL	PER WELD PROCEDURES		8
	1	62MP0312 OR EQUAL	PLUG, NYLON 6/6	MICRO PLASTIC INC. FLIPPIN, AR 72634		7
	1	-6	KAOLITE 1600 TM VIBRATED CAST	THERMAL CERAMICS AUGUSTA, GA 30903-0923		6
	4	-5	LIFTING INSERT	11/16 ROUND 304/304L SST	ASME SA479	5
	1	-4	PLUG RIM	16 GA SHT 304/304L SST	ASME SA240	4
	1	-3	BOTTOM SHEET	16 GA SHT 304/304L SST	ASME SA240	3
	1	-2	TOP SHEET	16 GA SHT 304/304L SST	ASME SA240	2
AR	X	-1	TOP PLUG WELDMENT			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

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Name: ROGER D. AIGNER Date: 2/10/05

REV	DESCRIPTION
B	GENERAL REVISION ADDED WELD SYMBOL
A	ISSUED FOR PROTOTYPE PROCUREMENT

P THIS DRAWING PRODUCED ON PRO/ENGINEER

SCALE: NOTED

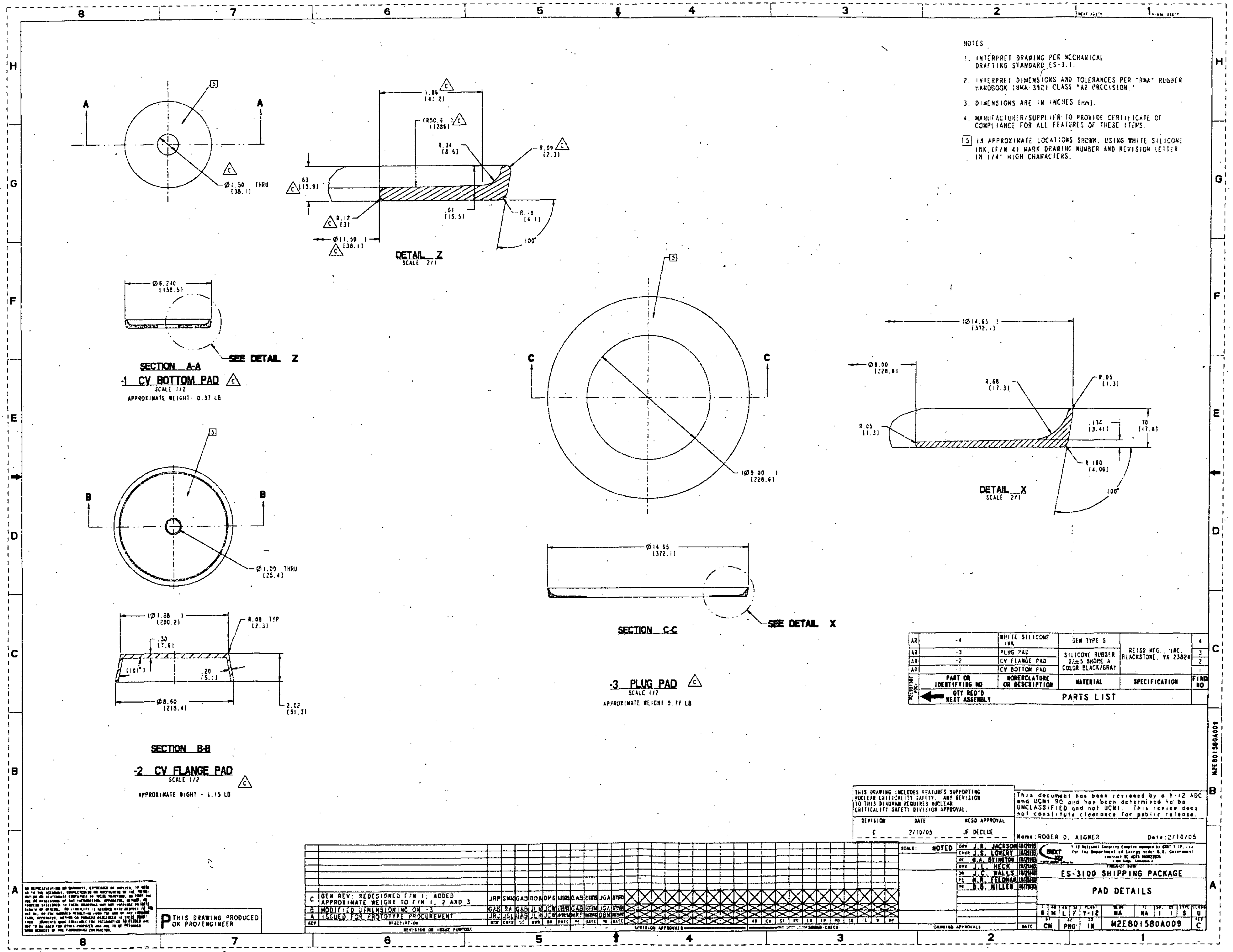
DRN J.R. JACKSON
CHKR J.S. LOWERY
DE G.A. BYINGTON
DYE J.L. HECK
DM J.C. WALLS
PC N.R. FELDMAN
PE D.H. MILLER

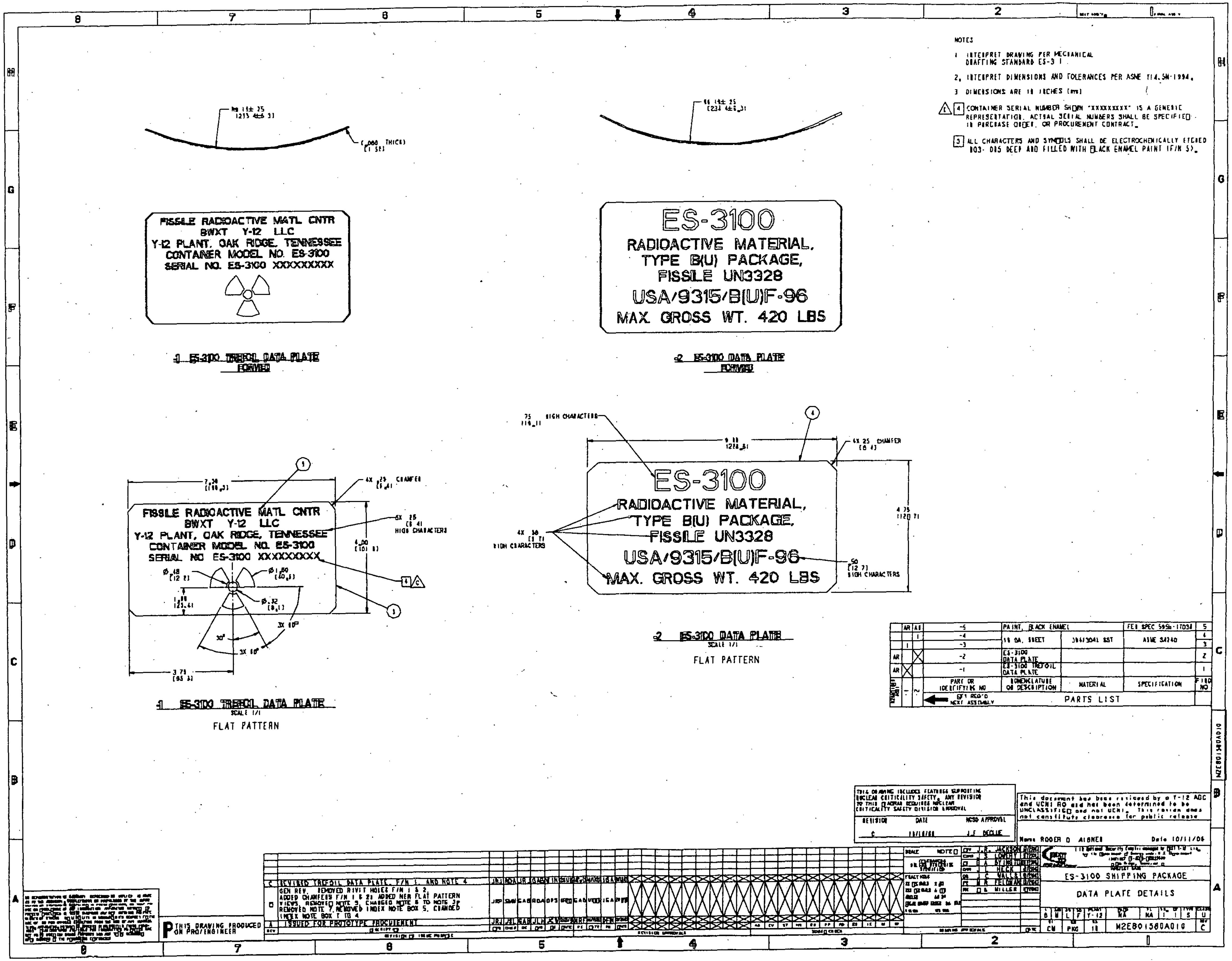
BWXT Y-12

ES-3100 SHIPPING PACKAGE

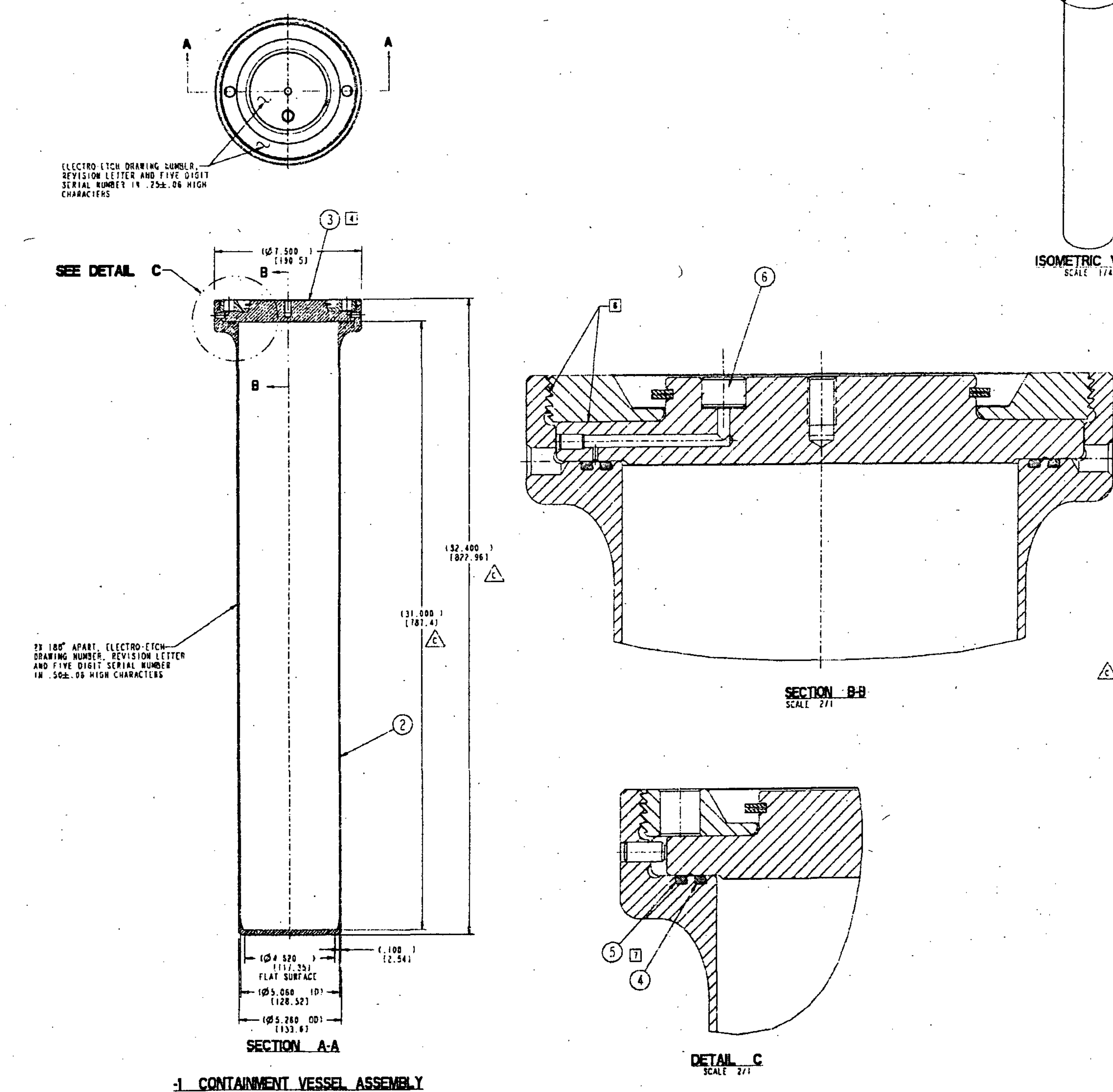
TOP PLUG WELDMENT

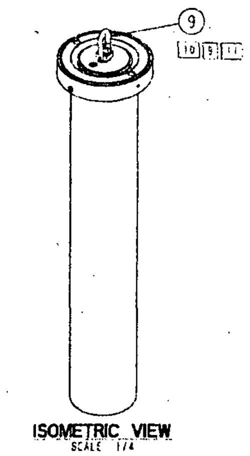
M2E801580A008 REV B


NOTES
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER "RMA" RUBBER HANDBOOK (RMA 3921 CLASS "A2 PRECISION."
3. DIMENSIONS ARE IN INCHES (mm).
4. MANUFACTURER/SUPPLIER TO PROVIDE CERTIFICATE OF COMPLIANCE FOR ALL FEATURES OF THESE ITEMS.
5 IN APPROXIMATE LOCATIONS SHOWN, USING WHITE SILICONE INK, (F/N 4) MARK DRAWING NUMBER AND REVISION LETTER IN 1/4" HIGH CHARACTERS.
DETAIL Z
SCALE 2/1
SECTION A-A
-1 CV BOTTOM PAD
SCALE 1/2
APPROXIMATE WEIGHT - 0.37 LB
SEE DETAIL Z
SECTION B-B
-2 CV FLANGE PAD
SCALE 1/2
APPROXIMATE WEIGHT - 1.15 LB
SECTION C-C
SEE DETAIL X
-3 PLUG PAD
SCALE 1/2
APPROXIMATE WEIGHT 5.77 LB
DETAIL X
SCALE 2/1
PARTS LIST
AR -4 WHITE SILICONE INK — SEM TYPE S — 4
AR -3 PLUG PAD — 3
AR -2 CV FLANGE PAD — 2
AR -1 CV BOTTOM PAD — 1
SILICONE RUBBER 72±5 SHORE A COLOR BLACK/GRAY
REISS MFG., INC. BLACKSTONE, VA 23824
PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO
QTY REQ'D NEXT ASSEMBLY
THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.
REVISION C DATE 2/10/05 NCSD APPROVAL JF DECLUE
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name: ROGER D. AIGNER Date: 2/10/05
C OER REV: REDESIGNED F/N 1; ADDED APPROXIMATE WEIGHT TO F/N 1, 2 AND 3
B MODIFIED DIMENSIONING ON -3
A ISSUED FOR PROTOTYPE PROCUREMENT
SCALE: NOTED
J.R. JACKSON
J.S. LOWERY
G.A. BYINGTON
J.L. HECK
J.C. WALLS
N.R. FELDMAN
D.B. MILLER
ES-3100 SHIPPING PACKAGE
PAD DETAILS
Y-12
M2E801580A009
C
THIS DRAWING PRODUCED ON PRO/ENGINEER



NOTES
1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3 1
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES (mm)
4 CONTAINER SERIAL NUMBER SHOWN "XXXXXXXXX" IS A GENERIC REPRESENTATION. ACTUAL SERIAL NUMBERS SHALL BE SPECIFIED IN PURCHASE ORDER, OR PROCUREMENT CONTRACT.
5 ALL CHARACTERS AND SYMBOLS SHALL BE ELECTROCHEMICALLY ETCHED .003-.005 DEEP AND FILLED WITH BLACK ENAMEL PAINT (F/N 5).
FISSILE RADIOACTIVE MATL CNTR
BWXT Y-12 LLC
Y-12 PLANT, OAK RIDGE, TENNESSEE
CONTAINER MODEL NO. ES-3100
SERIAL NO. ES-3100 XXXXXXXXX
-1 ES-3100 TREFOIL DATA PLATE FORMED
ES-3100
RADIOACTIVE MATERIAL,
TYPE B(U) PACKAGE,
FISSILE UN3328
USA/9315/B(U)F-96
MAX. GROSS WT. 420 LBS
-2 ES-3100 DATA PLATE FORMED
-2 ES-3100 DATA PLATE
SCALE 1/1
FLAT PATTERN
-1 ES-3100 TREFOIL DATA PLATE
SCALE 1/1
FLAT PATTERN
PAINT, BLACK ENAMEL
16 GA. SHEET
ES-3100 DATA PLATE
ES-3100 TREFOIL DATA PLATE
PARTS LIST
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name ROGER D. ALBNER
Date 10/11/06
ES-3100 SHIPPING PACKAGE
DATA PLATE DETAILS
M2E801580A010
REVISED TREFOIL DATA PLATE, F/N 1, AND NOTE 4
ISSUED FOR PROTOTYPE PROCUREMENT
THIS DRAWING PRODUCED ON PRO/ENGINEER





NOTES

1. INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3-1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3. DIMENSIONS ARE IN INCHES (mm).
4. INSTALL THE LID NUT AND TORQUE TO 120 ±5 FT-LBS AS SHOWN ON M2E801580A020-3 AND A020-4.
5. APPROXIMATE WEIGHT: 32.98 LBS. (14.96 KG)
6. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPEC. DS-YMH3-801580-A001.
7. DURING INSTALLATION OF O-RINGS APPLY A THIN COAT OF SUPER-O-LUBE.
8. DURING INSTALLATION OF CONTAINER VESSEL LID ASSEMBLY, APPLY A LIGHT COAT OF KRYTOX GREASE TO THE THREADS AND UNDER THE NUT.
9. SWIVEL HOIST RING FOR USE WHEN LOADING AND UNLOADING CONTAINMENT VESSEL ONLY. NOT FOR SHIPMENT.
10. TORQUE SWIVEL HOIST RING TO 12 ±1 FT-LBS. PER MFGR'S SPEC.
11. THE SWIVEL HOIST RING, THREAD LUBRICANT AND O-RING LUBRICANTS ARE REQUIRED AT EACH LOADING AND MAINTENANCE STATION.

QTY REQ'D	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
AR	3052T56 OR EQUAL	SWIVEL HOIST RING	ALLOY STEEL	McMASTER-CARR ATLANTA, GA	9
AR	KRYTOX 240AC OR EQUAL	THREAD LUBRICANT	FLUORINATED GREASE	MILLER-STEPHENSON CHEMICAL CO. DANBURY, CT 06810	8
AR	SUPER-O-LUBE OR EQUAL	O-RING LUBRICANT	CLEAR DIMETHYL SILOXANE POLYMER	PARKER HANNIFIN CORP. O-RING DIV.,PO BOX 11751 LEXINGTON, KY 40512	7
1	PART # 04-2126	MODIFIED VCO THREADED PLUG	BRASS	VOLUNTEER INDUSTRIAL P. O. BOX 30371 KNOXVILLE, TN 37930 PHONE 865-690-2617	6
1	M2E801580A013-2	O-RING, OUTER			5
1	M2E801580A013-1	O-RING, INNER			4
1	M2E801580A014-1	CONTAINMENT VESSEL LID ASSEMBLY			3
1	M2E801580A017-1 OR A012-4	CONTAINMENT VESSEL BODY ASSEMBLY			2
AR	-1	CONTAINMENT VESSEL ASSEMBLY			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
C	2/10/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER O. AIGNER Date: 2/10/05

REV	DESCRIPTION	DWN	CHKR	DE	DVD	DD	DATE	PE	DATE
C	GENERAL REVISION DELETED F/N 9; RENUMBERED F/N 10 TO NEW F/N 9; ADDED NOTE 11; NOTE 4 TORQUE WAS 100	JRP	SMG	GAB	RDA	DPS		GAB	
B	-1 WAS A FABRICATED PART, ADDED A012-4 WELDED CV OPTION	GAB	RA	GAB	JLH	JCW		GAB	
A	ISSUED FOR PROTOTYPE PROCUREMENT	JRJ	JSL	GAB	JLH	JCW		MRT	

REVISION OR ISSUE PURPOSE

P THIS DRAWING PRODUCED ON PRO/ENGINEER

SCALE: NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED

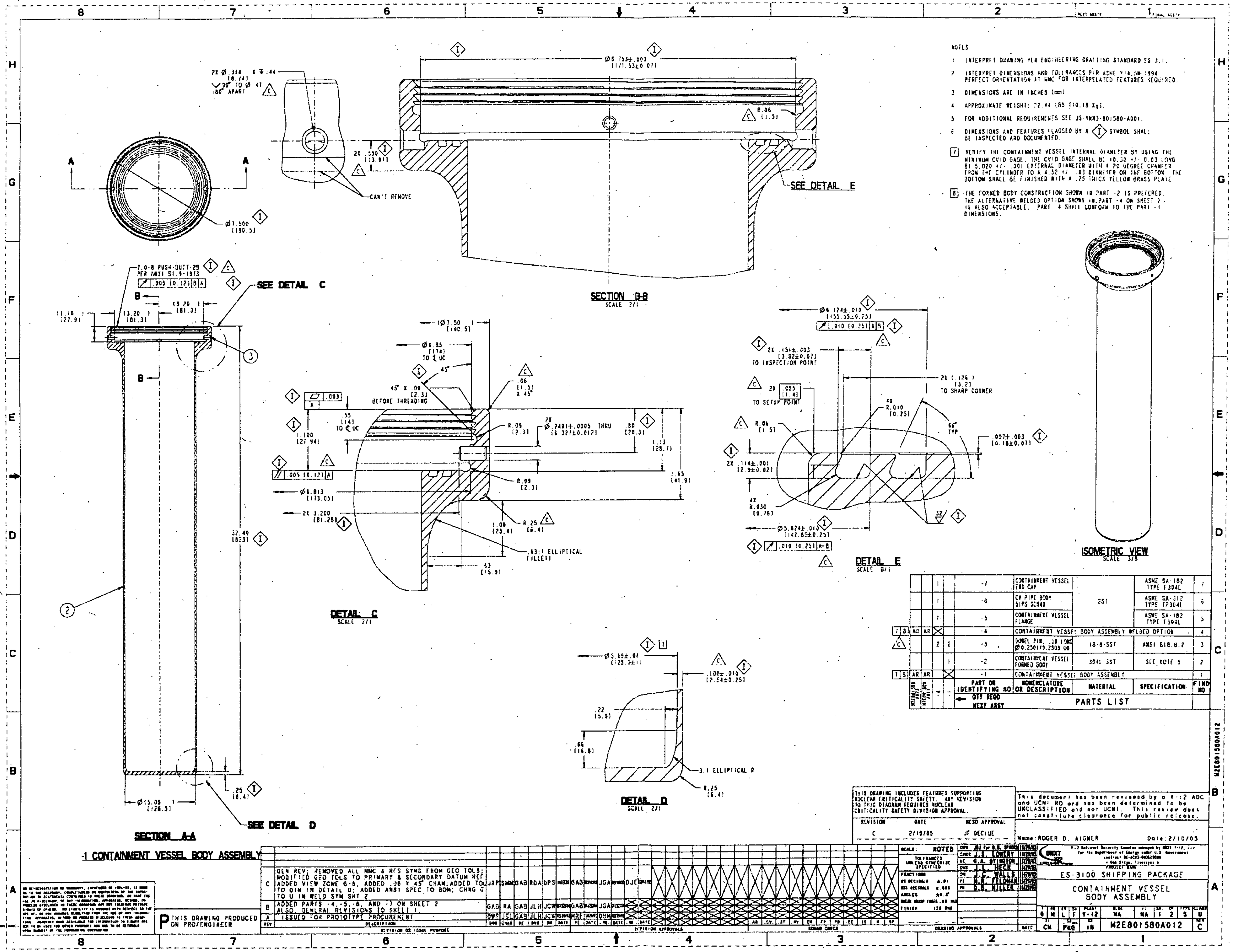
DRAWING APPROVALS: D.S. LOWERY; G.A. BYINGTON; J.L. HECK; J.C. WALLS; M.R. FELDMAN; D.D. MILLER

BWXT Y-12 — Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy, Oak Ridge, Tennessee

PROJECT NAME: ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL ASSEMBLY

0	M	L	F	Y-12	NA	NA	1	1	A	U
CN	PKG	IN	M2E801580A011							C



		1		-7	CONTAINMENT VESSEL END CAP	SST	ASME SA-182 TYPE F304L	7
		1		-6	CV PIPE BODY 5IPS SCH40	SST	ASME SA-312 TYPE TP304L	6
		1		-5	CONTAINMENT VESSEL FLANGE	SST	ASME SA-182 TYPE F304L	5
AR	AR	X		-4	CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION			4
		2	2	-3	DOWEL PIN, .50 LONG Ø0.2501/0.2503 OD	18-8-SST	ANSI B18.8.2	3
			1	-2	CONTAINMENT VESSEL FORMED BODY	304L SST	SEE NOTE 5	2
AR	AR		X	-1	CONTAINMENT VESSEL BODY ASSEMBLY			1
M2E801580A012	M2E801580A011	-4	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
← QTY REQD NEXT ASSY					PARTS LIST			

REV	DESCRIPTION	DRN	CHKD
C	GEN REV: REMOVED ALL MMC & RFS SYMS FROM GEO TOLS; MODIFIED GEO TOLS TO PRIMARY & SECONDARY DATUM REF ADDED VIEW ZONE G-6. ADDED .06 X 45° CHAM; ADDED TOL TO DIM IN DETAIL D; ADDED ANSI SPEC TO BOM; CHNG G TO U IN WELD SYM SHT 2	JRP	SMM
B	ADDED PARTS -4, -5, -6, AND -7 ON SHEET 2 ALSO, GENERAL REVISIONS TO SHEET 1	GAD	RA
A	ISSUED FOR PROTOTYPE PROCUREMENT	DWS	JSL

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
C	2/10/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date: 2/10/05

THIS DRAWING PRODUCED ON PRO/ENGINEER

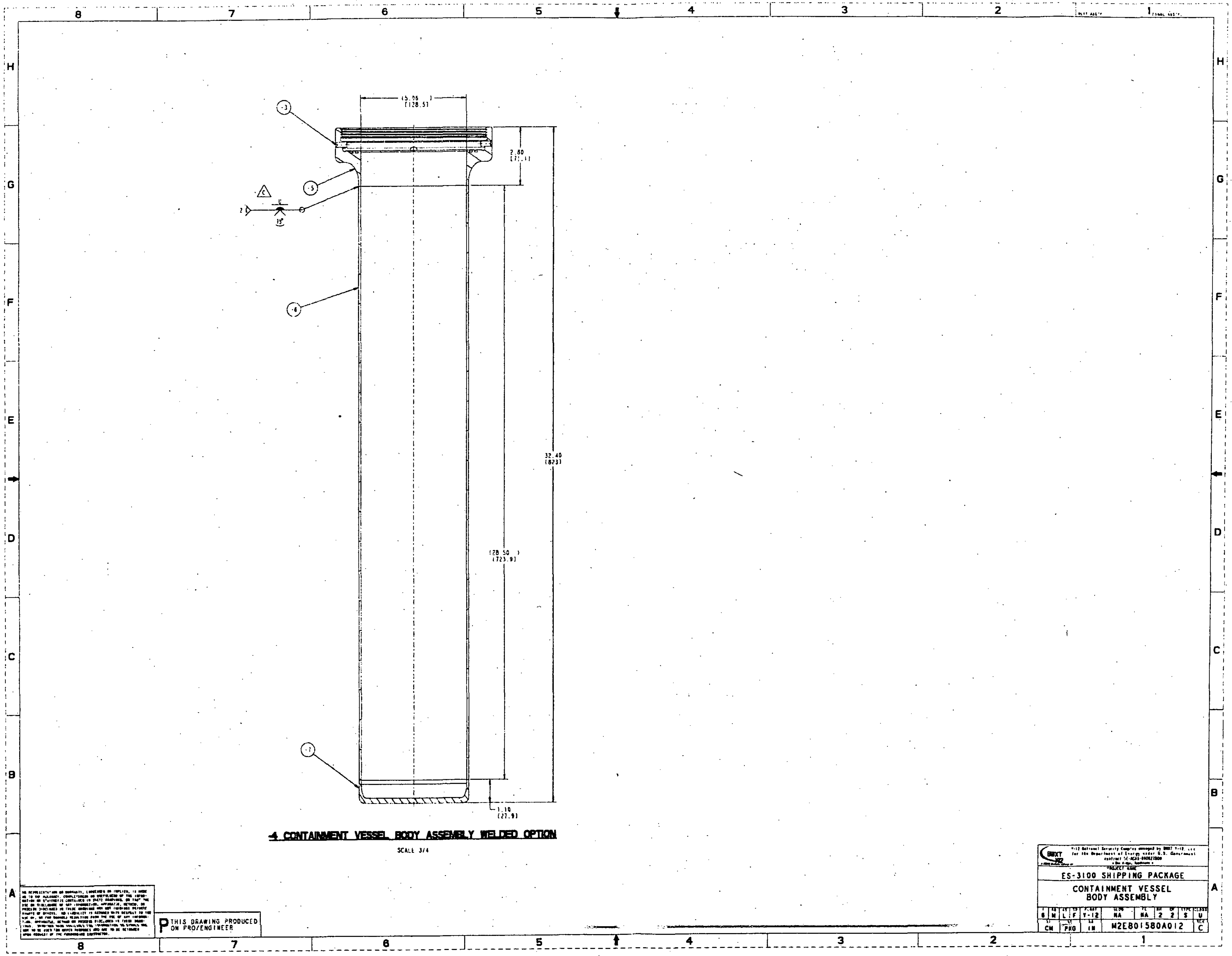
SCALE: NOTED

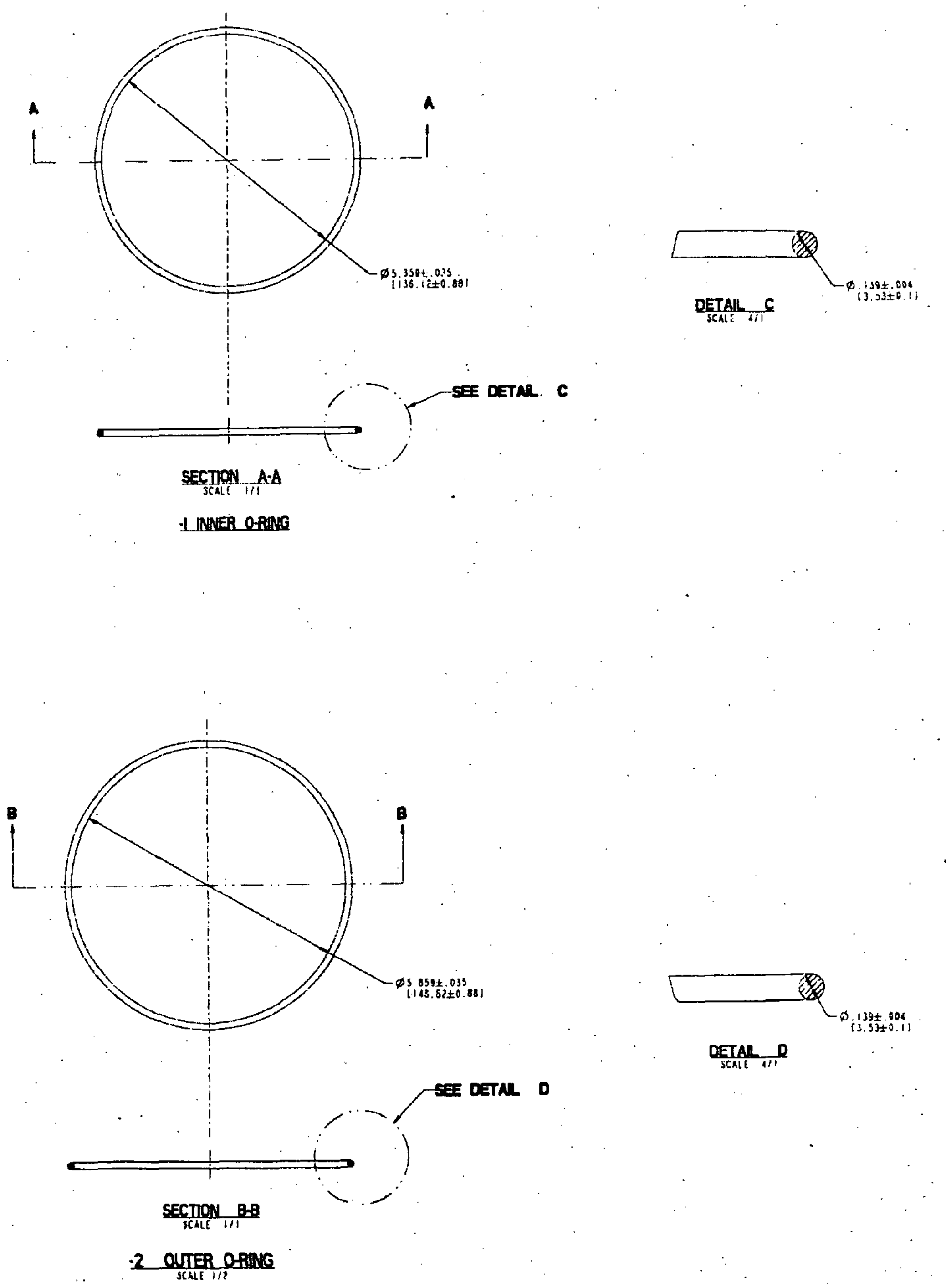
DRN J.S. LOWERY; G.A. BYINGTON; J.L. HECK; J.C. WALLS; N.R. FELDMAN; D.B. MILLER

ES-3100 SHIPPING PACKAGE

CONTAINMENT VESSEL BODY ASSEMBLY

M2E801580A012 REV C


(5.05)
(128.5)
2.80
(71.1)
32.40
(823)
(28.50)
(723.9)
1.10
(27.9)
-4 CONTAINMENT VESSEL BODY ASSEMBLY WELDED OPTION
SCALE 3/4
THIS DRAWING PRODUCED ON PRO/ENGINEER
ES-3100 SHIPPING PACKAGE
CONTAINMENT VESSEL
BODY ASSEMBLY
Y-12
NA
NA
2
2
S
U
CM
PRG
IN
M2E801580A012
C



NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES 3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DIMENSIONS ARE IN INCHES.(mm)
4. O-RING SHALL MEET THE FOLLOWING REQUIREMENTS IN ADDITION TO THE PROCUREMENT SPECIFICATION OO-PP-986.

TYPE OF SERVICE:	STATIC FACE SEAL
MATERIAL COMPOSITION:	ETHYLENE PROPYLENE:
COMPOUND SPECIFICATION:	ASTM D2000 M3BA712A14B13F17
(3) TEMPERATURE SERVICE RANGE:	302°F TO -40°F
HARDNESS:	70A +/- 5 SHORE A DUROMETER
ELONGATION %, MINIMUM:	100%
FABRICATION METHOD:	MOLDED
SURFACE CONDITION:	SMOOTH, NON POROUS, FREE OF SKIN DEFECTS
COLOR	BLACK

QTY REQD		PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
	AR	-2	OUTER O-RING	SEE NOTE 4		2
AR	AR	-1	INNER O-RING	SEE NOTE 4		1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
B	2/10/05	JF DECLUE

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: ROGER D. AIGNER Date: 2/10/05

REV	DESCRIPTION
B	GEN REV: -1 WAS 2-253; -2 WAS 2-257; 302°F WAS 300°F
A	ISSUED FOR PROTOTYPE PROCUREMENT

P THIS DRAWING PRODUCED ON PRO/ENGINEER

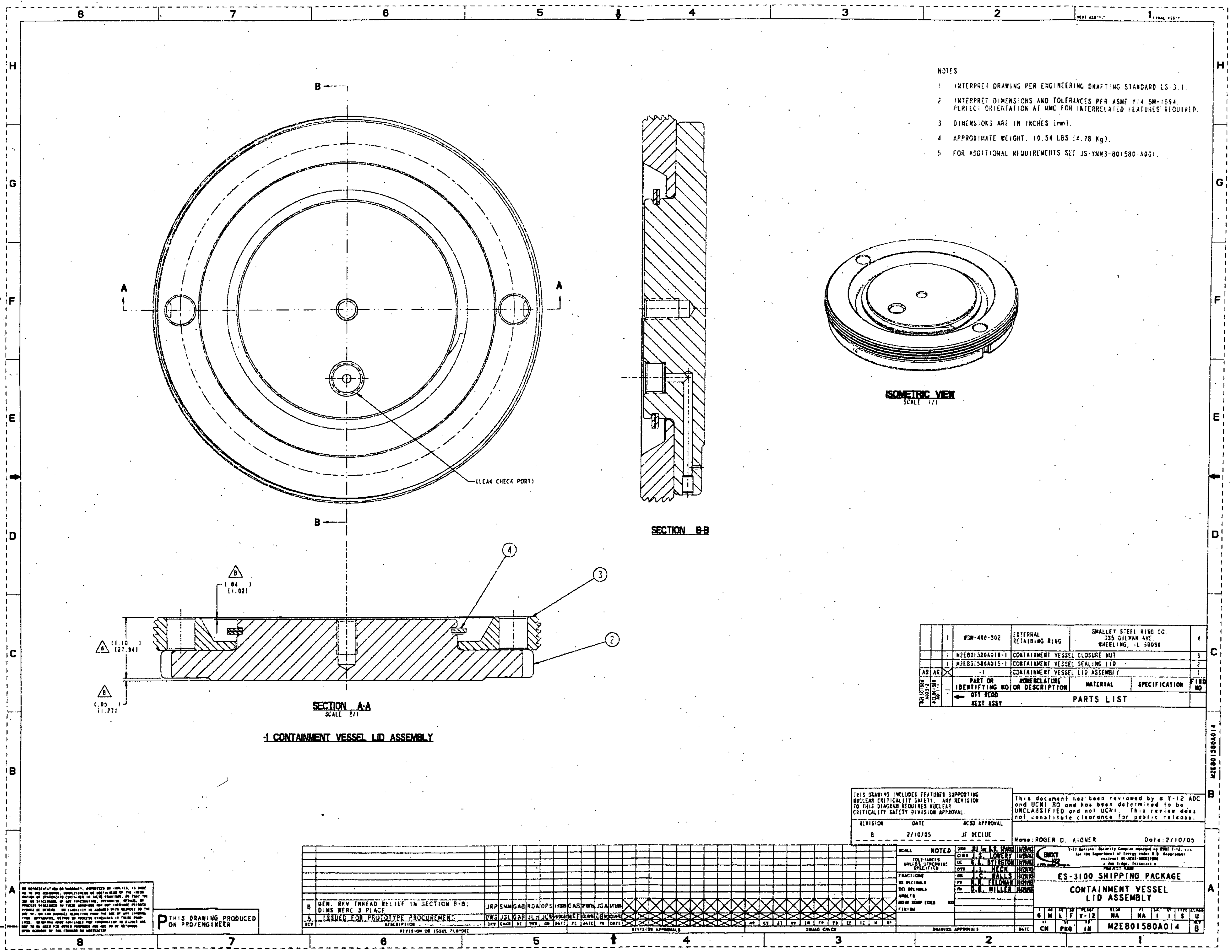
SCALE: NOTED

DRAWING APPROVALS: J.S. LOWERY; G.A. BYINGTON; J.L. HICKS; J.C. WALLS; H.R. FELDMAN; D.B. MILLER

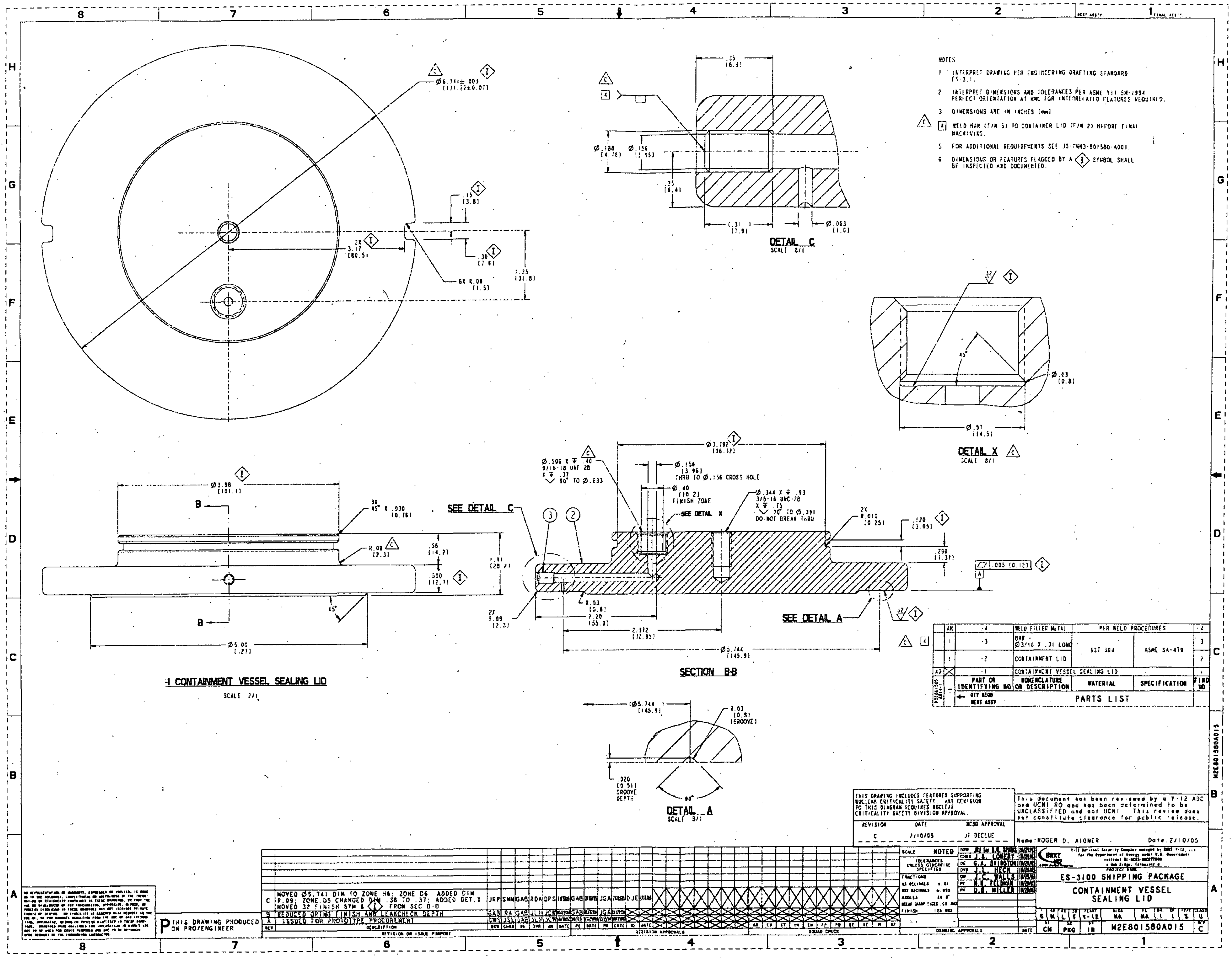
ES-3100 SHIPPING PACKAGE

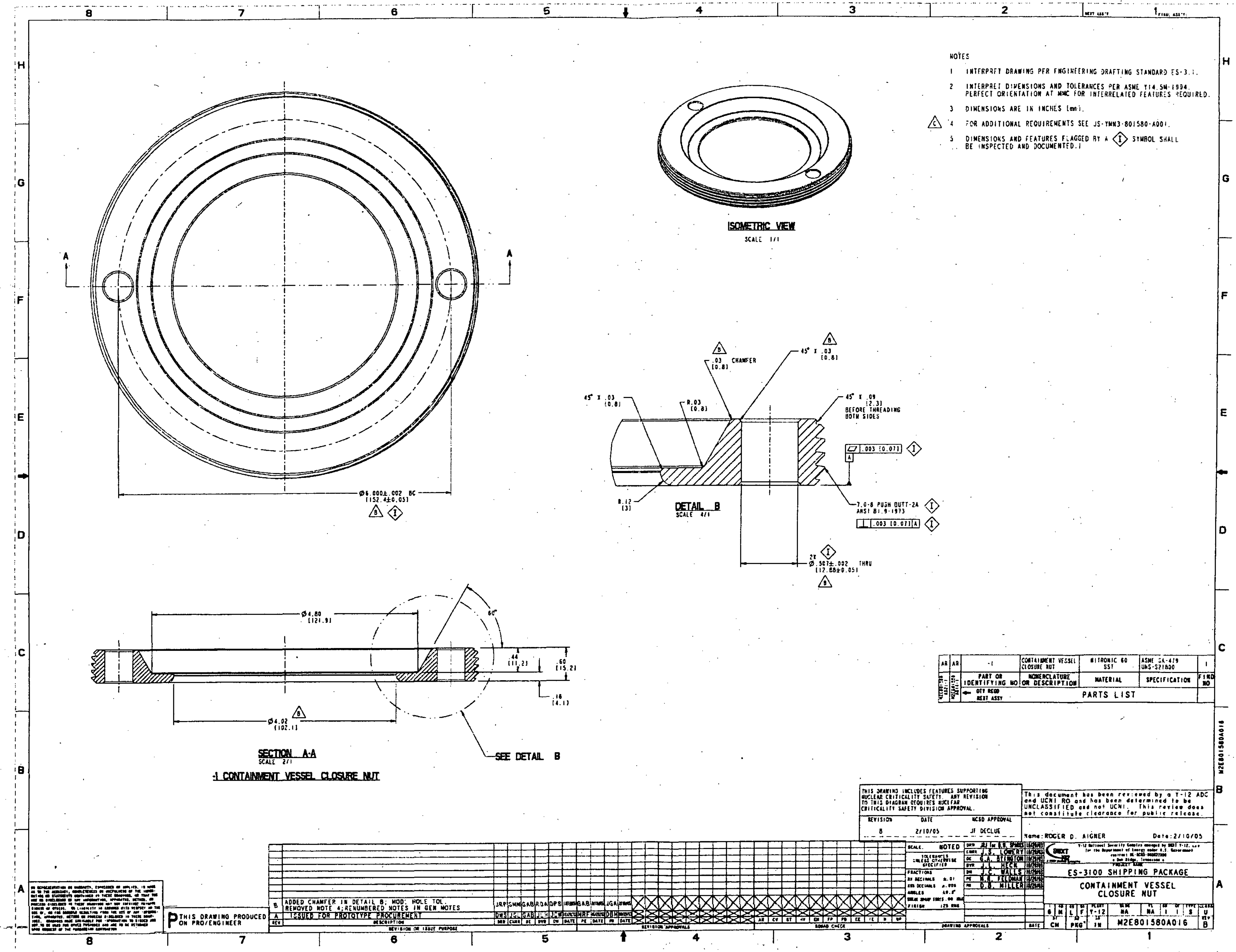
CONTAINMENT VESSEL O-RING DETAILS

M2E801580A013 REV B



NOTES
1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3 DIMENSIONS ARE IN INCHES (mm).
4 APPROXIMATE WEIGHT. 10.54 LBS (4.78 Kg).
5 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.
LEAK CHECK PORT
SECTION B-B
ISOMETRIC VIEW
SCALE 1/1
SECTION A-A
SCALE 3/1
-1 CONTAINMENT VESSEL LID ASSEMBLY
1 WSM-400-502 EXTERNAL RETAINING RING SMALLEY STEEL RING CO. 335 GILMAN AVE. WHEELING, IL 60090 4
1 M2E801580A016-1 CONTAINMENT VESSEL CLOSURE NUT 3
1 M2E801580A015-1 CONTAINMENT VESSEL SEALING LID 2
AR AR -1 CONTAINMENT VESSEL LID ASSEMBLY 1
PART OR IDENTIFYING NO
NOMENCLATURE OR DESCRIPTION
MATERIAL
SPECIFICATION
FIND NO
QTY REQD
NEXT ASSY
PARTS LIST
THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.
REVISION DATE NCSD APPROVAL
B 2/10/05 JF DECLUE
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name: ROGER D. AIGNER Date: 2/10/05
B GEN. REV THREAD RELIEF IN SECTION B-B; DIMS WERE 3 PLACE
A ISSUED FOR PROTOTYPE PROCUREMENT
THIS DRAWING PRODUCED ON PRO/ENGINEER
SCALE NOTED
J.S. LOWERY
G.A. BYINGTON
J.L. HECK
J.C. WALLS
D.B. MILLER
ES-3100 SHIPPING PACKAGE
CONTAINMENT VESSEL
LID ASSEMBLY
Y-12
CN PKG IN
M2E801580A014
B


SECTION B-B
DETAIL A
DETAIL C
DETAIL X
SEE DETAIL C
SEE DETAIL A
-1 CONTAINMENT VESSEL SEALING LID
PARTS LIST
THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.
REVISION C
DATE 2/10/05
NCSD APPROVAL JF DECLUE
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name: ROGER D. AIGNER
Date: 2/10/05
SCALE NOTED
ES-3100 SHIPPING PACKAGE
CONTAINMENT VESSEL
SEALING LID
M2E801580A015
THIS DRAWING PRODUCED ON PRO/ENGINEER


NOTES
1 INTERPRET DRAWING PER ENGINEERING DRAFTING STANDARD ES-3.1.
2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994. PERFECT ORIENTATION AT MMC FOR INTERRELATED FEATURES REQUIRED.
3 DIMENSIONS ARE IN INCHES [mm].
4 FOR ADDITIONAL REQUIREMENTS SEE JS-YMN3-801580-A001.
5 DIMENSIONS AND FEATURES FLAGGED BY A I SYMBOL SHALL BE INSPECTED AND DOCUMENTED.
ISOMETRIC VIEW
SCALE 1/1
Ø6.000±.002 BC
[152.4±0.05]
DETAIL B
SCALE 4/1
.03 CHAMFER
[0.8]
45° X .03
[0.8]
R.03
[0.8]
45° X .09
[2.3]
BEFORE THREADING
BOTH SIDES
R.12
[3]
.003 [0.07]
7.0-8 PUSH BUTT-2A
ANSI B1.9-1973
.003 [0.07] A
2X
Ø.507±.002 THRU
[12.88±0.05]
Ø4.80
[121.9]
Ø4.02
[102.1]
60°
.44
[11.2]
.60
[15.2]
.16
[4.1]
SECTION A-A
SCALE 2/1
-1 CONTAINMENT VESSEL CLOSURE NUT
SEE DETAIL B
AR | AR | -1 | CONTAINMENT VESSEL CLOSURE NUT | NITRONIC 60 SST | ASME SA-479 UNS-S21800 | 1
QTY REQD NEXT ASSY | PART OR IDENTIFYING NO | NOMENCLATURE OR DESCRIPTION | MATERIAL | SPECIFICATION | FIND NO
PARTS LIST
THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.
REVISION B DATE 2/10/05 NCSD APPROVAL JF DECLUE
This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.
Name: ROGER D. AIGNER Date: 2/10/05
THIS DRAWING PRODUCED ON PRO/ENGINEER
B ADDED CHAMFER IN DETAIL B; MOD. HOLE TOL. REMOVED NOTE 4; RENUMBERED NOTES IN GEN NOTES
A ISSUED FOR PROTOTYPE PROCUREMENT
REV DESCRIPTION
REVISION OR ISSUE PURPOSE
SCALE NOTED
J.S. LOWERY
G.A. ATTINGTON
J.L. HECK
J.C. WALLS
N.R. FELDMAN
D.B. MILLER
DRAWING APPROVALS
ES-3100 SHIPPING PACKAGE
CONTAINMENT VESSEL
CLOSURE NUT
Y-12
M2E801580A016
B

NOTES

1 INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.

2 INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.

3 DIMENSIONS ARE IN INCHES.

[4] FOR FURTHER INFORMATION, SEE EQUIPMENT SPECIFICATION DS-YMN3-801580-A005, CASTING CATALOG NO. 277-4 NEUTRON ABSORBER.

[5] FOR PURCHASE OF F/N 8, SEE DOCUMENT #DS-YMN3-801580-A001.

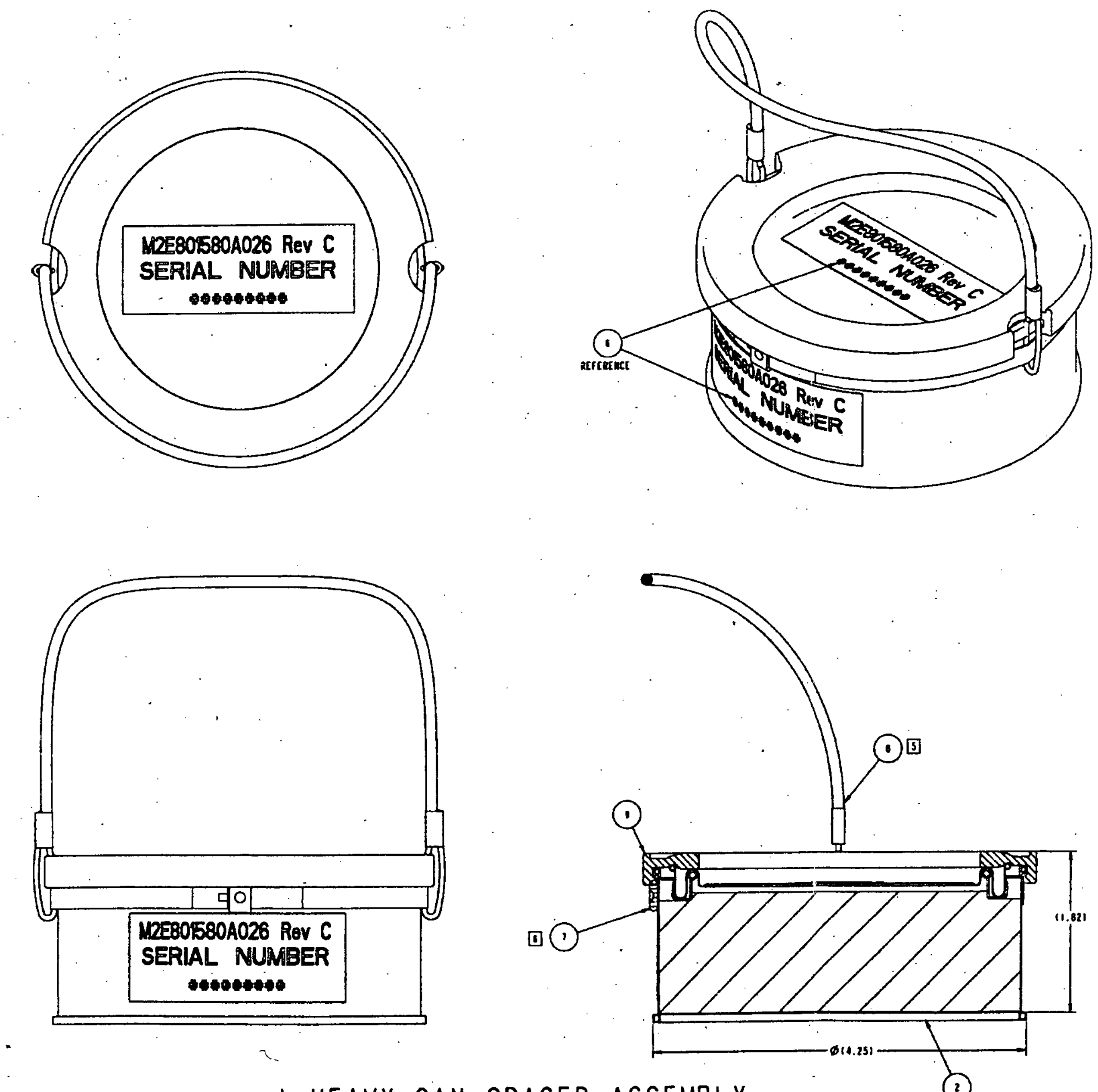
[6] USE THE BAND-IT TIE-LOCK II HAND TOOL "A920" TO ATTACH THE STAINLESS STEEL BANDS AND CABLE ASSEMBLIES TO THE MATERIAL CANS. THE TOOL'S TENSION SETTING SHALL BE SET BETWEEN 4 AND 8.

7 REFERENCE DOCUMENT #DAC-YMN3-801580-A001.

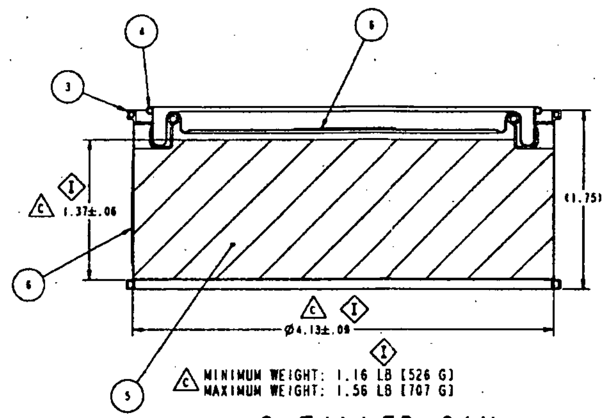
(C) 8 FOR REFERENCE ONLY FIND NO 1; NOMINAL WEIGHT: 1.38 LBS [0.626 KG]

9 DIMENSIONS AND FEATURES FLAGGED BY SYMBOL ⟨I⟩ SHALL BE INSPECTED AND DOCUMENTED. THESE DIMENSIONS ARE OF CRITICALITY SAFETY CONCERNS AND SHALL NOT BE DEVIATED WITHOUT PRIOR APPROVAL.

[10] MARK WITH PERMANENT LABELS F/N 6 DRAWING NUMBER, REVISION LETTER AND SIX DIGIT SERIAL NUMBER IN .18±.03 HIGH CHARACTERS.



(C) -1 HEAVY CAN SPACER ASSEMBLY
SCALE 2/1



(C) -2 FILLED CAN
SECTION B-B
SCALE 2/1

Note	M2E801580A035	M2E801580A027	-2	-1	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
				1	M2E801580A024-1	VIBRATION ABSORBING SILICONE 4.25" CAN PAD			9
[5]				1	-8	CABLE LANYARD	REFERENCE NOTE 5		8
[6]				1	AS213	BAND CLAMP	304 SST	BAND-IT-IDEX, INC. DENVER, CO 80216	7
[10]			2		WL-OL875WJ OR EQUAL	2.625" BY 1" VINYL COATED WEATHERPROOF WHITE PRINTER LABELS		WORLDLABEL.COM 338 CONVERT AVE, STE 2A NEW YORK NY 10031 SALES (866) 226-6669	6
[4]			1		-5	277-4 FILLER		DS-YMN3-801580-A005	5
(C)			1		-4	CAN LID	10 oz. (4-1/4" X 1-3/4") DOUBLE-FRICTION CAN STOCK NUMBER 5051 OR EQUAL	FREUND CONTAINER 11535 S. CENTRAL AVE ALSIP, IL 60803 PHONE: 800.363.9822	4
(C)			1		-3	CAN BASE			3
(C)			X	1	-2	FILLED CAN			2
	AR	AR		X	-1	HEAVY CAN SPACER ASSEMBLY			1

← QTY REQ'D NEXT ASSEMBLY — PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DIAGRAM REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL.

REVISION	DATE	NCSD APPROVAL
C	1/25/2006	J. E. DeClue

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name: Roger D. Aigner Date: 01/26/06

REV	DESCRIPTION	DWN	CHKR	DE	DVE	EM	DATE	PE	DATE	PM	DATE
C	CHANGED CAN SIZE FROM 8 OZ TO 10 OZ	GAB	HMJ	GAB	RDA	MLG		GAB			
B	REDESIGNED, ADDED NEW ASSEMBLY F/N 2 AND MODIFIED PARTS LISTS AND NOTES.	JRP	SMM	GAB	RDA	DPS		GAB		JGA	
A	ISSUED FOR PROTOTYPE PROCUREMENT	RDA	JSL	GAB	JLH	JCW		GAB		GBS	

REVISION OR ISSUE PURPOSE

SCALE: NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED: FRACTIONS, XX DECIMALS, XXX DECIMALS, ANGLES, BREAK SHARP EDGES, FINISH

DRAWING APPROVALS: DWN R.D. AIGNER; CHKR J.S. LOWERY; DE G.A. BYINGTON; DVE J.L. HECK; EM J.C. WALLS; PE G.A. BYINGTON; PM G.B. SINGLETON

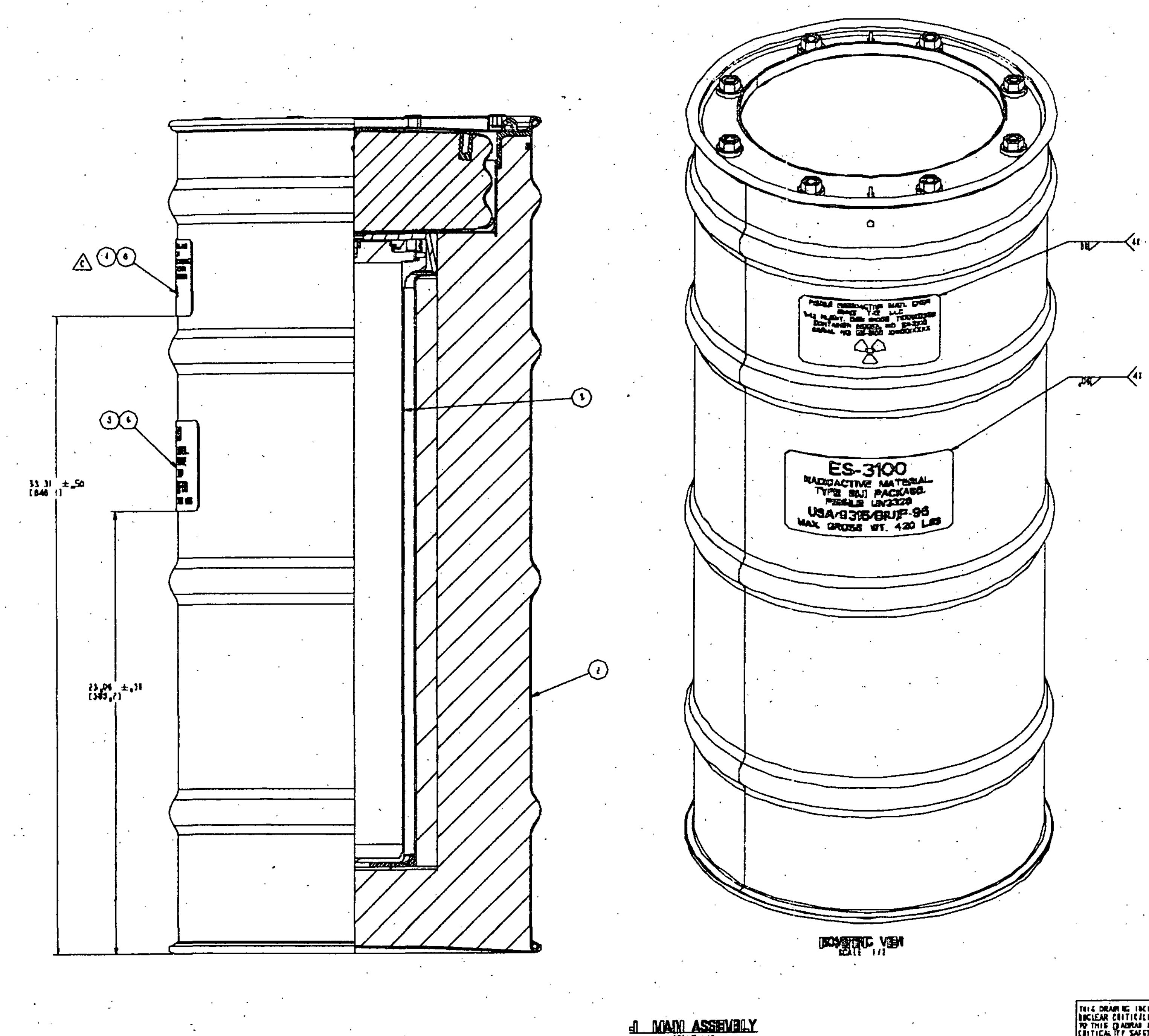
Y-12 National Security Complex managed by BWXT Y-12, L.L.C. for the Department of Energy under U.S. Government contract DE-AC05-00OR22800 • Oak Ridge, Tennessee •

PROJECT NAME: ES-3100 SHIPPING PACKAGE

HEAVY CAN SPACER ASSEMBLY

				PLANT	BLDG	FL	SH.	OF	TYPE	CLASS
B	M	L.	F.	Y-12	NA	NA	1	1	S	U
CM	PKG	IN	M2E801580A026							C

P THIS DRAWING PRODUCED ON PRO/ENGINEER



NOTES

1. INTERPRET DRAWING PER MECHANICAL DRAFTING STANDARD ES-3.1.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994
3. DIMENSIONS ARE IN INCHES [mm]
4. APPROXIMATE WEIGHT: 323.8 LBS [146.9 Kg]
5. FOR ADDITIONAL REQUIREMENTS SEE EQUIPMENT SPECIFICATION JS-YMN3-801580-A002.
6. WELDING SYMBOLS SHALL BE INTERPRETED IN ACCORDANCE WITH AWS A2.4.

	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION	FIND NO
AR	-6	WELD FILLER METAL			6
1	M2E801580A010-2	ES-3100 DATA PLATE			5
1	M2E801580A010-1	ES-3100 TREFOIL DATA PLATE			4
1	M2E801580A011-1	CONTAINMENT VESSEL ASSEMBLY			3
1	M2E801580A001-1	DRUM ASSEMBLY			2
X	-1	MAIN ASSEMBLY			1

PARTS LIST

THIS DRAWING INCLUDES FEATURES SUPPORTING NUCLEAR CRITICALITY SAFETY. ANY REVISION TO THIS DRAWING REQUIRES NUCLEAR CRITICALITY SAFETY DIVISION APPROVAL

REVISION	DATE	NCSD APPROVAL
C	10/11/06	J.F. DeClue

This document has been reviewed by a Y-12 ADC and UCNI RO and has been determined to be UNCLASSIFIED and not UCNI. This review does not constitute clearance for public release.

Name ROGER D. AISNER Date 10/11/06

REV	DESCRIPTION
C	REVISED TREFOIL DATA PLATE
B	GEN REV. CHG NOTE 4, ADDED NOTES 5 & 6, CHG FIND 6 PAG BLIND RIVIT HEIGHTS & VOLS IN NOTE 10 UPDATED TO REFLECT NEW MAT'L
A	ISSUED FOR PROTOTYPE PROCUREMENT

THIS DRAWING PRODUCED ON PRO/ENGINEER

J. R. JACKSON; J. S. LOWERY; D. A. DYBISON; J. L. HECK; J. C. VALLE; M. R. FELDMAN; D. G. MILLER

ES-3100 SHIPPING PACKAGE

MAIN ASSEMBLY

Y-12 | NA | NA | M2E801580A031 | REV C

M2E801580A031

APPENDIX 1.4.9

DESIGN ANALYSES AND CALCULATIONS, DAC-PKG-801624-A001, MIXING WEIGHTS AND ELEMENTAL COMPOSITION OF 277-4 NEUTRON POISON USED IN THE ES-3100

Design Analyses and Calculations

Title Page	
Calculation No.:	DAC-PKG-801624-A001
Calculation Title:	Mixing Weights And Elemental Composition Of 277-4 Neutron Poison used in the ES-3100
Preparer's Organization:	Packaging Engineering
Project/Task Name:	ES-3100 Shipping Package
Record Number:	Y2003-0328
Rev.:	B

Comments/Purpose: The purpose of this DAC is to enable a tight quality control on the amount of neutron poison materials used in each shipping package.

Printed Name and Signature

Prepared By:	G. A. Byington /s/	Date:	10/11/06
Checked/Verified By:	John F DeClue /s/	Date:	10/17/06
Checked/Verified By:	James H. Clinton /s/	Date:	10/23/2006
Discipline Manager Approval:	W. I. North /s/	Date:	10/23/06

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

Name: Roger D. Aigner /s/ Date: 11/8/06

Revision Log

Rev	Date	Description	Total Pages	Affected Pages
0	January 18, 2006	Initial issue	Front matter, 1-3 Body 4-21 Appendix 1, 22-24 Appendix 2, 24	All
A	January 20, 2006	Removed Report references and Updated Tables 10, 11, 12, and 13.	Front matter, 1-3 Body 4-21 Appendix 1, 22-24 Appendix 2, 24	4, 10, 18, 19, 20
B	October 12, 2006	Updated Table 7, 277-4 Composition @ Extreme Densities and LOD%. Updated DAC format to new log. New DAC format applied.	Front matter, 1-3 Body 4-22 Appendix 1, 23-24 Appendix 2, 25	1, 2, 14

Table of Contents

1. Objective

The purpose of this DAC is to define the amounts of materials to mix and manufacture the borated cement neutron poison used in the ES-3100 Shipping Container as one batch per shipping container. The exact amount of B_4C added to be the mixture shall be calculated in this design analysis to be greater than 7.61×10^{20} atoms/cc of ^{10}B at the minimum density and maximum hydration. This elemental analysis of the minimum value of ^{10}B was used in the ES-3100 SAR Criticality Safety calculations.

2. Purpose

By adding the proper amount of boron carbide in each ES-3100 Shipping Container mass balanced, assuming thorough mixing, macro homogeneity is obtained. This will enable a tight quality control on the amount of neutron poison materials used in each shipping package.

3. References

The ES-3100 Shipping Container is placed in BWXT Y-12 National Security Complex drawing M2E801580A002 following Equipment Specification JS-YMN3-8015580-A005. Two sample cans are taken during each shipping package pouring of the casting into drawing M2E801580A026-2.

4. Materials to Mix

4.1. B_4C

Boron carbide (B_4C) powder shall be procured as Type 1 Nuclear-Grade Boron Carbide Powder per ASTM C 750-03 shipped in sealed steel containers. An approximate partial size of 106 micrometers (0.0041 inches) is generated by having 100% of the grit pass through a No. 140 Sieve per ASTM E 11. A copy of the chemical and elemental analysis purity shall be in accordance with ASTM C 791.

4.2. 277-0

Thermo Electron's proprietary Catalog No. 277 – Heat Resistant Shielding (with no Boron), is a type of high alumina cement and will be referred to as 277-0. The manufactures information can be found in Appendix 1 & 2. This dry powder shall be shipped in sealed open head steel drums and has no shelf life limitations if keep dry and free flowing. Once the container is opened it shall be discarded if clumps or lumps are observed in the material greater than 0.5 inches.

4.3. Water

The water shall be potable, filtered through a 20-micron filter, and have a chlorine content of less than 4 ppm. If the potable water's chlorine content is higher then 4 ppm, use an activated charcoal filter or some other means to reduce the amount of chlorine below 4 ppm.

5. Scope of Calculations

The bounding elemental calculations shall be completed at the minimum ^{10}B level for the compositional purity, isotopic atomic percentage, and scale measurements.

5.1. Amount of B_4C in 277-4 Borated High Alumina Cement

Define the method for mixing 277-4 as a two part method of 277-0 and B_4C and calculate the volumetric atomic concentrations.

5.2. 277-4 Borated High Alumina Cement at Extreme Conditions

Calculate the minimum amount of B_4C to add to the 277-4 mixture to generate a volumetric atomic concentration greater than 7.61×10^{20} atoms/cc of ^{10}B at the minimum density and maximum hydration.

5.3. ^{10}B Areal Density at Minimum ^{10}B Content and Density

Calculate the ^{10}B Areal Density between the fissile mass loads in two adjacent shipping packages.

5.4. Volumetric Atomic Concentrations at Average Density and LOD%

Calculate the average density and hydration volumetric atomic concentrations.

5.5. Extreme Densities and LOD% Volumetric Atomic Concentrations

Calculate the extreme density and hydration volumetric atomic concentrations.

5.6. Define the Masses Needed To Mix a Batch of 277-4 For a ES-3100

Calculate the mass weights used to mix a batch used in one ES-3100.

5.7. Define the Volumetric Atomic Concentrations at NCT and HAC

At higher temperatures especially above 212°F the chemically unbound or free water will leave the cast cement. Using the minimum boron mixer weights calculated in Section 7.2 define the NCT and HAC volumetric atomic concentrations at a minimum manufactured density, hydration for the calculated temperatures.

5.8. Define the Nominal Volumetric Atomic Concentrations

Using nominal mixer weights from Section 7.6 calculate the nominal ^{10}B content.

6. Base Material Elemental Volumetric Concentrations

6.1. Boron Carbide Powder B_4C

The elemental composition weight percents of B_4C must be defined per ASTM C 750-03, using Type 1 Nuclear-Grade Boron Carbide Powder as noted in Table 1 from ASTM C 750-03.

TABLE 1 Chemical Requirements

Constituent	Composition, Weight %[A]		
	Type 1	Type 2	Type 3
Total boron[B]	81.0 max 76.5 min	81.0 max 73.0 min	81.0 max 70.0 min
HNO_3-soluble boron	0.5 max	0.6 max	not determined
Water soluble boron	0.2 max	0.2 max	1.0 max
Fluoride	25 µg/g max	25 µg/g max	not determined
Chloride	75 µg/g max	75 µg/g max	not determined
Calcium	0.3 max	0.3 max	not determined
Iron	1.0 max	1.0 max	2.0 max
Total boron plus total carbon	98.0 min	97.0 min	94.0 min

[A]Unless otherwise indicated (percentages based on a dry weight of boron carbide).

[B]Unless otherwise specified, the ^{10}B isotopic content in the boron shall be 19.90 ± 0.3 atom % for Types 1 and 2 and 19.90 ± 0.5 atom % for Type 3.

Find the minimum ^{10}B weight percents using ASTM C 750-03 Type 1 at ^{10}B equal to 19.9±0.3 atom % of natural boron (NatB).

At the minimum 19.6 atom % of ^{10}B the ^{11}B would be 100-19.6 = 80.4 atom %.

Using the molecular weights of ^{10}B the ^{11}B:
B10 = 10.0129370×19.6% = 1.962535652 (g/mol)
B11 = 11.0093055×80.4% = 8.851481622 (g/mol)
NatB = B10 + B11 = 1.962535652 + 8.851481622 (g/mol)
NatB = 10.81401727% (g/mol) Min per ASTM C 750-03 Type 1

B10 wt% = B10 / NatB = 1.962535652 / 10.81401727
B10 wt% = 18.14807211 wt% Min per ASTM C 750-03 Type 1

Using the minimum total natural boron of 76.5 wt% the following weight percentages are calculated.

B10 wt% = 76.5% × 18.148 wt%
B10 wt% = 13.883 wt%

B11 wt% = 76.5 − 13.883 wt%
B11 wt% = 62.617 wt%

One of the largest B_4C impurities in Table 1 is the nitric acid (HNO_3). As shown in Table 4 the 277-4 neutron poison solid requires hydrogen and contains a large amount of oxygen. Therefore, a conservative approximation shall be to change the balance of the weight percents from 0.5 to 0.7 wt% and make up the difference with nitrous trioxide (NO_3) removing the hydrogen from this impurity.

Determine the weight percents of nitrous trioxide (NO_3)
NO_3 = MW(N) + 3×MW(O) (g/mol)
NO_3 = 14.0067 + 3×15.9949 (g/mol)
NO_3 = 61.9914 (g/mol)

N wt% = 14.0067 / 61.9914
N wt% = 0.225946 wt%

For 0.7 wt% NO_3
N wt% = 0.225946 % ×0.7 wt%
N wt% = 0.158 wt%

O wt% = NO_3 wt% − N wt%
O wt% = 0.7 − 0.158 wt%
O wt% = 0.542 wt%

Table 2, Nuclear-Grade Boron Carbide Powder Elemental Composition Weight Percents

Element	At.wt (g/mol)	B_4C (wt%)
Hydrogen	1.0078	
B Nat	10.8140	
^{10}B	10.0129	13.883%
^{11}B	11.0093	62.617%
Carbon	12.0000	21.500%
Nitrogen	14.0067	0.158%
Oxygen	15.9949	0.542%
Sodium	22.9895	
Magnesium	24.3051	
Aluminum	26.9818	
Silicon	28.0853	
Sulfur	32.0636	
Calcium	40.0803	0.300%
Iron	55.8447	1.000%
Sum		100.000%

6.2. Catalog No. 277 – Heat Resistant Shielding With no Boron (277-0)

Verify the hydrogen elemental composition weight percent of Thermo Electron's proprietary Catalog No. 277 – Heat Resistant Shielding using the density of 1.61 g/cc (100.509 lb/ft^3), also called 277-0. Used the published weight percents for No. 277 – Heat Resistant Shielding with no boron and calculate the hydrogen atoms per cc. According to Appendix 2; Thermo Electron Corp. Heat Resistant Shielding Catalog No. 277 Typical Elemental Analysis Without Boron, EA-277, May 1988.

Table 3, Catalog No. 277 – Heat Resistant Shielding Elemental Composition for one ft^3

Element	At.wt (g/mol)	(wt%)	(lb/ft^3)	N_e (Atoms/cc)
Hydrogen	1.0078	3.730%	3.749	3.588E+22
B Nat	10.8140			
^{10}B	10.0129			
^{11}B	11.0093			
Carbon	12.0000			
Nitrogen	14.0067			
Oxygen	15.9949	59.140%	59.441	3.585E+22
Sodium	22.9895	0.080%	0.080	3.374E+19
Magnesium	24.3051	0.230%	0.231	9.175E+19
Aluminum	26.9818	26.590%	26.725	9.555E+21
Silicon	28.0853	1.680%	1.689	5.800E+20
Sulfur	32.0636	0.210%	0.211	6.350E+19
Calcium	40.0803	8.040%	8.081	1.945E+21
Iron	55.8447	0.300%	0.302	5.209E+19
Sum		100.00%	100.509	

The calculated value of hydrogen atoms per cc matched the recorded value in the typical elemental analysis of Catalog No. 277 – Heat Resistant Shieiding. The following calculations use the molecular weights; Hydrogen 1.0078 g/mol, Oxygen 15.9994 g/mol, and water 18.0153 g/mol.

One must now determine how much water is in this solid casting. Water within the cast solid is defined in a water weight "Loss On Drying" (LOD) test in a weight percent of the initial density. The LOD% is calculated based upon the amount of hydrogen.

LOD% = H wt% × (MW H_2O) / (MW H_2)
LOD% = 3.730% × (18.0150 / (2× 1.0078)
LOD% = 33.338% as defined by the manufacture

$$H\ (lb/ft^3) = \frac{277\ \text{cast density}(lb/ft^3) \times \text{LOD wt\%} \times (2 \times \text{H Mw (g/mol)})}{\text{Water Mw (g/mol)}}$$

$$H\ (lb/ft^3) = \frac{277\ \text{cast density}(lb/ft^3) \times \text{LOD wt\%} \times (2 \times 1.0078\ \text{(g/mol)})}{18.0153\ \text{(g/mol)}}$$

$$H\ (lb/ft^3) = 277\ \text{cast density}(lb/ft^3) \times \text{LOD wt\%} \times 0.1118826775$$

The volumetric atomic concentrations are calculated below.

$$\text{H atoms/cc} = \frac{((\text{H density(lb/ft}^3)) \times (N_A \text{ atoms/mol}))}{(\text{H Mw (g/mol)} \times (62.42796\ (\text{lb/ft}^3)/(\text{g/cc}))}$$

$$\text{H atoms/cc} = \frac{((\text{H density(lb/ft}^3)) \times (6.0221415\times10^{23} \text{ atoms/mol}))}{(1.0078\ (\text{g/mol}) \times (62.42796\ (\text{lb/ft}^3)/(\text{g/cc}))}$$

$$\text{H atoms/cc} = ((\text{H density(lb/ft}^3)) \times 9.571884693\times10^{21}(\text{H atoms/cc})/(\text{lb/ft}^3)$$

$$\text{H atoms/cc} = (277 \text{ cast den (lb/ft}^3) \times \text{LOD wt\%} \times 0.1118826775) \times 9.571884693\times10^{21}(\text{H atoms/cc})/(\text{lb/ft}^3)$$

$$\text{H atoms/cc} = (277 \text{ cast density (lb/ft}^3) \times \text{LOD wt\%}) \times 1.070928088\times10^{21}(\text{H atoms/cc})/(\text{lb/ft}^3)$$

$$\text{H atoms/cc} = (100.509\ (\text{lb/ft}^3) \times 33.338 \text{ wt\%}) \times 1.070928088\times10^{21}(\text{H atoms/cc})/(\text{lb/ft}^3)$$
$$\text{H atoms/cc} = 3.588432683\times10^{22} \text{ atoms/cc}$$

This calculated hydrogen elemental composition compares well to the documented value found in Appendix 2.

Using the hydrogen density the volume of water in the casting may be calculated as a fraction of Specific Gravity.
@ H = 3.749 (lb/ft^3)

$$\text{SGF} = \text{H (lb/ft}^3) \times \text{Water Mw (g/mol)} / ((2 \times \text{H Mw (g/mol)} \times \text{Water density (lb/ft}^3))$$
$$\text{SGF} = \text{H (lb/ft}^3) \times 18.0153\ (\text{g/mol}) / ((2 \times 1.0078\ (\text{g/mol})) \times 62.42796\ (\text{lb/ft}^3))$$
$$\text{SGF} = \text{H (lb/ft}^3) \times 0.143172$$
$$\text{SGF} = 3.749\ (\text{lb/ft}^3) \times 0.143172\ (1/(\text{lb/ft}^3))$$
$$\text{SGF} = 0.53675$$

Or the casting is 53.67% water by volume

7. Calculations

7.1. Amount of B_4C in 277-4 Borated High Alumina Cement

The boron carbide powder and Catalog No. 277 – Heat Resistant Shielding materials must now be combined to generate our neutron poison called 277-4 borated high alumina cement. An iterative solution was used to calculate the density of the 277-4 using the single component weight percents. First the mass amount of boron carbide powder must be selected and volume calculated. The B_4C volume is subtracted from one cubic foot to determine the volume of 277-0 cement. From the 277-0 cement volume the mass is calculated and all of the components' masses. As more boron carbide powder is added to the mixture it gets heavier and reduces the amount of relative hydrogen available to the neutron poison system in the cement.

Select or guess a mass of 5.88 lbs of B_4C for one cubic foot of casting with a theoretical density of 2.52 g/cc (157.318 lb/ft^3), found in the CRC Handbook of Chemistry and Physics, 55th Ed., page B-74. Verify this amount of B_4C needed in Section 7.2.

Calculate the volume of B_4C;
B4C vol = Mass (lb) / Den (lb/ft^3)
B4C vol = 5.88 lb / 157.318 lb/ft^3
B4C vol = 0.03738 ft^3

Calculate the volume and mass of the 277-0 material using the density of 1.61 g/cc (100.509 lb/ft^3).

277-0 vol = 1 - 0.03738 ft^3
277-0 vol = 0.96262 ft^3

277-0 mass = 0.96262 ft^3×100.509 lb/ft^3
277-0 mass = 96.7523 lb

Table 4, 277-4 Borated High Alumina Cement Elemental Composition for one ft^3

Element	At.wt (g/mol)	277-0 (lb/ft^3)	B_4C (lb/ft^3)	277-4 (lb/ft^3)
Hydrogen	1.0078	3.6089	0.0000	3.6089
B Nat	10.8140			
^{10}B	10.0129	0.0000	0.8163	0.8163
^{11}B	11.0093	0.0000	3.6819	3.6819
Carbon	12.0000	0.0000	1.2642	1.2642
Nitrogen	14.0067	0.0000	0.0093	0.0093
Oxygen	15.9949	57.2193	0.0319	57.2512
Sodium	22.9895	0.0774	0.0000	0.0774
Magnesium	24.3051	0.2225	0.0000	0.2225
Aluminum	26.9818	25.7264	0.0000	25.7264
Silicon	28.0853	1.6254	0.0000	1.6254
Sulfur	32.0636	0.2032	0.0000	0.2032
Calcium	40.0803	7.7789	0.0176	7.7965
Iron	55.8447	0.2903	0.0588	0.3491
Sum		96.7523	5.8800	102.6323

Calculate the as-defined by the manufacture and mixed to this ratio LOD%.
H wt% = H lb/ft^3 / Total Mass lb/ft^3
H wt% = 3.6089 / 102.6323
H wt% = 3.5163 wt%

LOD% = H wt% × (MW H_2O) / (MW H_2)
LOD% = 3.5163 wt% × (18.0150 / (2× 1.0078)
LOD% = 31.4279 wt%

7.2. 277-4 Borated High Alumina Cement at Extreme Conditions

The casting process overloads the mixture with water to allow the wet mix to flow. Dependent upon the amount of surface area and curing conditions of the casting the water content varies. As the water content varies both oxygen and hydrogen elemental masses change while the other solid masses stay fixed from in the matrix shown in Table 4. The left most density column in Table 5 shows the adjusted hydrogen and oxygen masses to a LOD% of 31.8%, while keeping all the other elemental concentrations the same. At this calculated LOD% the weight percent is calculated. Due to the possibility of small air bubbles the density could also vary. Therefore the calculated LOD% weight percents can now be multiplied by a density to generate the elemental volumetric concentrations at any LOD%. From the elemental volumetric concentration the atomic concentrations are calculated at the selected LOD% and density. Testing has shown that 99.7% of the 277-4 companion sample can castings will have an LOD% of 30.2%±1.6% and density of 105±5 lb/ft^3. Although, the ES-3100 drum has a larger casting with small percentage of the surface open to the air. The small open surface to volume ratio keep the 277-4 casting hydrated. Three castings that have been stored in an office environment for over a year had a density of 123 lb/ft^3. The difference being water content measured by the LOD% testing. This extra water make the 277-4 work better. Therefore, we would not want to overly reduce the extra moisture. An acceptable density range for this material shall be 105 −5+15 lb/ft^3 has been selected.

To calculate the elemental weight percents at a different LOD% like 31.8% another iterative calculation is required to adjust the volumetric concentrations of water. Assume a LOD% for Table 4 was 31.9735%

Delta LOD% = 31.9735% − 31.4279%
Delta LOD% = 0.5456%

Therefore for one cubic foot the water loss or gain from the definition in Table 4 is;
Del WW = Delta LOD% × Tab4Den × Volume
Del WW = 0.5456% × 102.6323 (lb/ft^3) × 1 (ft^3)
Del WW = 0.5599 lb

The amount of hydrogen weight change in a cubic foot is;
Del H = Del WW × (MW H_2) / MW H_2O
Del H = 0.5599 × (2×1.0078) / 18.0150
Del H = 0.0626 lb

Del O = Del WW − Del H
Del O = 0.5599 − 0.0626
Del O = 0.4973 lb

All values in the left column of Table 5 are same as the 277-4 masses in Table 4 except that the Hydrogen has gained 0.0626 lb and the Oxygen has gain 0.4973 lb. Using the new Table 5 elemental volumetric concentrations the weight percents are calculated. The elemental weight percents are multiplied by a desired density. The minimum acceptable density based upon testing is 100 lb/ft^3.

Table 5, 277-4 Elemental Composition @ 100 lb/ft^3 & 31.8% LOD as manufactured

Element	@LOD% (lb/ft^3)	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.6715	3.5579%	3.5579	3.406E+22
B Nat				
^{10}B	0.8163	0.7911%	0.7911	7.621E+20
^{11}B	3.6819	3.5680%	3.5680	3.126E+21
Carbon	1.2642	1.2251%	1.2251	9.848E+20
Nitrogen	0.0093	0.0090%	0.0090	6.207E+18
Oxygen	57.7485	55.9620%	55.9620	3.375E+22
Sodium	0.0774	0.0750%	0.0750	3.147E+19
Magnesium	0.2225	0.2156%	0.2156	8.559E+19
Aluminum	25.7264	24.9306%	24.9306	8.913E+21
Silicon	1.6254	1.5752%	1.5752	5.410E+20
Sulfur	0.2032	0.1969%	0.1969	5.924E+19
Calcium	7.7965	7.5553%	7.5553	1.818E+21
Iron	0.3491	0.3383%	0.3383	5.843E+19
Sum	103.1923	100.0000%	100.0000	8.419E+22

B Nat	4.4982	4.3590%	4.3590	3.888E+21

The minimum amount of B_4C added to be the mixture shall be calculated to be greater than 7.61×10^{20} atoms/cc of ^{10}B at the minimum density and maximum hydration as defined in Section 5.1.

7.3. Calculate the ^{10}B Areal Density at Minimum ^{10}B Content and Density

The ^{10}B Areal Density for one cylinder casting thickness of 1.12 inches (2.8448 cm)
B10 Areal Density = (B10 atoms/cc × Thickness cm) × (B10 Mw g/mol / N_A atoms/mol)

$$\text{B10 Areal Den} = \frac{7.621\times10^{20}\ (\text{B10 atoms/cc}) \times (2.8448\ \text{cm}) \times (10.0129370\ \text{g/mol})}{6.0221415 \times 10^{23}\ \text{atoms/mol}}$$

B10 Areal Den = 0.0360474235 g/cm^2 for one thickness

Between two packages next to each other in the most reactive arrangement the fissile mass loads are separated by two cast neutron poison cylinders.
B10 Areal Den = 0.0360474235 × 2
B10 Areal Den = 0.072094847 g/cm^2
B10 Areal Den = 72.09 mg/cm^2

7.4. Volumetric Atomic Concentrations at Average Density and LOD%

Using the same methodology shown in Section 7.1 the volumetric atomic concentrations shall be calculated at the average density and LOD%. The average LOD% of 30.2% and density should be 105 −5+15 lb/ft^3 shall be used and shown in Table 6.

Table 6, 277-4 Elemental Composition @ 105 lb/ft^3 & 30.2% LOD as manufactured

Element	@LOD% (lb/ft^3)	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.4068	3.3789%	3.5479	3.396E+22
B Nat				
^{10}B	0.8163	0.8096%	0.8501	8.190E+20
^{11}B	3.6819	3.6517%	3.8343	3.360E+21
Carbon	1.2642	1.2538%	1.3165	1.058E+21
Nitrogen	0.0093	0.0092%	0.0097	6.670E+18
Oxygen	55.6477	55.1913%	57.9509	3.495E+22
Sodium	0.0774	0.0768%	0.0806	3.382E+19
Magnesium	0.2225	0.2207%	0.2317	9.198E+19
Aluminum	25.7264	25.5155%	26.7913	9.578E+21
Silicon	1.6254	1.6121%	1.6927	5.814E+20
Sulfur	0.2032	0.2015%	0.2116	6.366E+19
Calcium	7.7965	7.7326%	8.1192	1.954E+21
Iron	0.3491	0.3462%	0.3635	6.279E+19
Sum	100.8268	100.0000%	105.0000	8.652E+22
B Nat	4.4982	4.4613%	4.6844	4.179E+21

7.5. Extreme Densities and LOD% Volumetric Atomic Concentrations

The high density is base upon both the hydration and compaction or the amount of entrapped air, if any. The ES-3100 shipping package 277-4 neutron poison cylinder castings hold the moisture well. This moisture is a key part of how the 277-4 neutron poison works. Therefore, it has been decided to accept the 277-4 neutron poison casting up to 120 lb/ft^3 making the density range 100 to 120 lb/ft^3. Most of the companion sample cans will have a density close to 105 lb/ft^3 while the cylinders are expected to be dried to just below the 120 lb/ft^3 limit, therefore density should be 105 −5+15 lb/ft^3. Using the calculation method in Section 7.1 the extreme densities and hydration levels atomic concentrations were calculated (Table 7).

Table 7, 277-4 Composition @ Extreme Densities and LOD% and compared to the average values as manufactured

Den (lb/ft³)	^{10}B (wt%)	^{10}B (atoms/cc)	B Nat (wt%)	B Nat (atoms/cc)	LOD (wt%)	H (wt%)	H (atoms/cc)
100.0	0.7911%	7.621E+20	4.359%	3.888E+21	31.80%	3.5579%	3.406E+22
105.0	0.7534%	7.621E+20	4.152%	3.888E+21	35.05%	3.9212%	3.941E+22
110.0	0.7192%	7.621E+20	3.963%	3.888E+21	38.00%	4.2516%	4.477E+22
115.0	0.6879%	7.621E+20	3.791%	3.888E+21	40.69%	4.5531%	5.012E+22
120.0	0.6592%	7.621E+20	3.633%	3.888E+21	43.17%	4.8296%	5.547E+22
105.0	0.8096%	8.190E+20	4.461%	4.179E+21	30.20%	3.3789%	3.396E+22
100.0	0.8282%	7.979E+20	4.564%	4.071E+21	28.60%	3.1999%	3.063E+22
105.0	0.8440%	8.538E+20	4.651%	4.356E+21	27.24%	3.0475%	3.063E+22
110.0	0.8584%	9.096E+20	4.730%	4.641E+21	26.00%	2.9090%	3.063E+22
115.0	0.8715%	9.655E+20	4.802%	4.926E+21	24.87%	2.7825%	3.063E+22
120.0	0.8835%	1.021E+21	4.868%	5.211E+21	23.83%	2.6666%	3.063E+22

7.6. Mass of Materials Needed To Mix a Batch of 277-4 For One ES-3100

The as define 277-4 mixture shown in Table 4 shall be the bases for the two part dry mixing recipe. The amount of B_4C added to be the mixture shall be calculated to be greater than 7.61×10^{20} atoms/cc of ^{10}B at the minimum density and maximum hydration as shown in Section 7.2. Now the amount of water, B_4C and Thermo Electron's proprietary Catalog No. 277 – Heat Resistant Shielding (277-0) dry powder must be calculated per shipping container.

According to Appendix 1; Thermo Electron Corp. Heat Resistant Shielding Catalog No. 277 product information sheet 277-103:

96 lbs of dry mix is required to obtain one cubic foot.
Required water is 27±1% of the total dry powder weight.

From Section 7.1 for one cubic foot the volume and mass of B_4C is 0.03738 ft³, 5.88 lb at a density of 157.318 lb/ft³. The 277-0 materials volume and mass is 0.96262 ft³, 96.7523 lb a density of 100.509 lb/ft³. Together this mixture generated a total density of 102.6323 lb/ft³.

For one cubic foot Cast Volume
277-4 Vol = Vol B_4C + Vol 277-0
277-4 Vol = 0.03738 + 0.96262 ft³
277-4 Vol = 1.00000 ft³

For one cubic foot Cast Mass for one cubic foot
277-4 Mass = Mass B_4C + Mass 277-0
277-4 Mass = 5.88 + 96.7523 lb
277-4 Mass = 102.6323 lb for one cubic foot

Using the 96 lbs of dry mix required to obtain 1 ft^3 calculate the mass of 277-0 dry mix required for this casting.
277-0 Dry Mix Mass = Vol 277-0 × Dry Mix Density
277-0 Dry Mix Mass = 0.96262 ft^3 × (96 lb/ft^3)
277-0 Dry Mix Mass = 0.96262 ft^3 × (96 lb/ft^3)
277-0 Dry Mix Mass = 92.4115 lb

The 277-0 dry mix plus the B_4C mass required for one cubic foot casting is;
277-4 Dry Mix Mass = 277-0 Dry Mix Mass × Mass B_4C
277-4 Dry Mix Mass = 92.4115 + 5.88 lb
277-4 Dry Mix Mass = 98.2915 lb

Defining the calculated mass as percent weight one gets;
Dry Mix B_4C wt% = Mass B_4C / 277-4 Dry Mix Mass
Dry Mix B_4C wt% = 5.88 / 98.2915 × 100%
Dry Mix B_4C wt% = 5.9822%

277-0 Dry Mix wt% = 100% − Dry Mix B_4C wt%
277-0 Dry Mix wt% = 100% − 5.9822%
277-0 Dry Mix wt% = 94.0178%

For a 50 lb 277-4 Dry Mix Mass calculate the weights of 277-0 Dry Mix, B_4C, and water;
Dry Mix B_4C = 5.9822% × 50 lb
Dry Mix B_4C = 2.9911 lb

277-0 Dry Mix = 94.0178%× 50 lb
277-0 Dry Mix = 47.0089 lb

The divisions on the scale used to weigh the 277-0 Dry Mix are every 0.2 lbs. I will assume that the tolerance on the measurement is 0.1%.
Therefore, the maximum scale error could be;
Max Scale Error = Mass × 0.001 + 0.1
Max Scale Error = 47.0089× 0.001 + 0.1
Max Scale Error = 0.147 lb

To assure the minimum amount of ^{10}B the maximum amount of cement must be controlled. Therefore the Maximum 277-0 Dry Mix mass should be;
Max 277-0 Dry Mix = 277-0 Dry Mix − Max Scale Error
Max 277-0 Dry Mix = 47.0089 − 0.147 lb
Max 277-0 Dry Mix = 46.8619 lb

Since the scales divisions are every 0.2 lbs the maximum 277-0 mass is;
Max 277-0 Dry Mix = 46.80 lb (for the scales)
Should be weigh on a small scale with divisions of at least 0.20 lb

The Dry Mix B_4C for a 50 lb 277-4 Dry Mix Mass would be;
Dry Mix B_4C = 50.00 − 46.80 lb
Dry Mix B_4C = 3.20 lb
Should be weigh on a small scale with divisions of at least 0.01 lb

Defining the scale mass as percent weight one gets;
Dry Mix B_4C wt% = Mass B_4C / 277-4 (Dry Mix Mass)
Dry Mix B_4C wt% = 3.20 / 50 × 100%
Dry Mix B_4C wt% = 6.40%

277-0 Dry Mix wt% = 100% − 6.40%
277-0 Dry Mix wt% = 93.60%

Mixing water required for the 50 lb dry mix bag at 27±1% dry mix weight.
Water Mix Weight = 277-4 Dry Mix Mass × 27%
Water Mix Weight = 50.0 × 27%
Water Mix Weight = 13.50 lb

Table 8, 277-4 Dry Mixing weights for one ES-3100

277-0 Dry Mix wt		Dry Mix B_4C		277-4 Dry Mix Mass		Water Mix Weight	
Mass	Scale Div	Mass	Scale Div	Mass	Scale Div	Mass	Scale Div
46.80	0.20	3.20	0.01	50.00	NA	13.50	0.2

Using the maximum total natural boron of 76.5 wt% calculate the weight percentage of natural boron in the dry powder mix.

NatB = B_4C wt% × 76.5 wt%
NatB = 6.4% × 76.5 wt%
NatB = 4.896 wt%

7.7. Define the Volumetric Atomic Concentrations at NCT and HAC

Testing of cast 277-4 shows that our sample cans will be dehydrated at elevated temperatures. Twenty five sample cans were tested at 250°F for 168 hours for the Normal Conditions of Transport (NCT). Then after weighing them they were heated to 320°F for 4 hours for the Hypothetical Accidental Conditions (HAC). Then after weighing them they were heated to 1475°F for 4 hours to totally dehydrate them. This test information has defined the change in hydration from the "as manufactured" to a worst case NCT and the worst case HAC. As the water was removed the cast solids density was also reduced.

Specific Gravity Fraction of water
SGF = H (lb/ft^3) × 0.143172 ($1/(lb/ft^3)$)
SGF = 3.531 (lb/ft^3) × 0.143172 ($1/(lb/ft^3)$)
SGF = 0.5055
On the average the castings are 50.55% water by volume.

Inversely the hydrogen weight concentration is calculated by;
H (lb/ft^3) = SGF / 0.143172

The as manufactured 277-4 casting has an amount of water that was measured with "Lost On Drying" (LOD) tests. Sample cans were placed in an oven at 250°F for 168 hours the weights were measured and after an additional heating to 320°F for 4 hours the weights were measured again. From those weights the amount of water was calculated and presented in Table 9 as a fractional specific gravity of hydration levels generated at different conditions were calculated to be;

Table 9, 277-4 Average Affects Of Temperature Conditions on 25 Tested Cans

	As Manufactured	NCT (250°F @ 168 hours)	HAC (NCT+320°F @ 4 hours)
SG	0.5055	0.4445	0.4435
H (lb/ft^3)	3.531	3.105	3.098
H (wt%)	3.378%	3.083%	3.078%
Percent H (%)	100%	87.93%	87.73%
Ave Density (lb/ft^3)	104.51	100.70	100.64

Therefore, the 277-4 cast solid material at NCT values has 87.93% the hydrogen of the as manufactured material and at HAC values has 87.73% the hydrogen of the as manufactured material. The reduction in hydrogen of water weight affect both the hydrogen and oxygen content in the 277-4 cast solid material. The as manufactured data in Table 6 277-4 Elemental Composition @ 105 lb/ft^3 & 30.2% LOD matches the average hydrogen weight percent in Table 9. In order to generate the minimum density and minimum hydrogen calculation the calculation method in section 7.4 must be modified.

The minimum as manufactured density is 100 lb/ft^3. Only the water weight in the form of hydrogen and oxygen is reduced by leaving the casting matrix. The hydrogen weight percent should also be reduced from the minimum manufactured value of 100% to 87.93% for NCT and 87.73% for HAC. This water mass reduction must be applied at the minimum density and hydrogen content. Table 7 has two different extreme values for ^{10}B and hydrogen. The affects of extended temperature extremes must be evaluated for both conditions. The conservation of mass shall be used for these calculations keeping the lb/ft^3 of the minerals the same while the weight percents change as the hydration level does.

The minimum hydrogen of 3.1999% occurs at a 28.60% LOD and 100 lb/ft^3 density shown in Tables 7 and 10. Therefore, using the data from Table 9 the hydrogen concentration would be reduced by the percentage;
Minimum Manufactured H wt%= 3.1999% Table 10

NCT Hydrogen wt% = 3.1999% × 87.93%
NCT Hydrogen wt% = 2.8137% Table 11

HAC Hydrogen wt% = 3.1999% × 87.73%
HAC Hydrogen wt% = 2.8073% Table 12

The minimum ^{10}B mixture has hydrogen at 3.5579%, and it occurs at a 31.80% LOD and 100 lb/ft^3 density. Therefore, using the data from Table 9 the hydrogen concentration would be reduced by the percentage;

Minimum Manufactured H wt%= 3.5579% Table 5

NCT Hydrogen wt% = 3.5579% × 87.93%
NCT Hydrogen wt% = 3.1284% Table 13

HAC Hydrogen wt% = 3.5579% × 87.73%
HAC Hydrogen wt% = 3.1213% Table 14

Table 10, 277-4 Manufactured Minimum Density @ Minimum Hydrogen
277-4 Elemental Composition @ 100 lb/ft^3 & 28.6% LOD

Element	@LOD% (lb/ft^3)	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.1541	3.1999%	3.1999	3.063E+22
B Nat				
^{10}B	0.8163	0.8282%	0.8282	7.979E+20
^{11}B	3.6819	3.7354%	3.7354	3.273E+21
Carbon	1.2642	1.2826%	1.2826	1.031E+21
Nitrogen	0.0093	0.0094%	0.0094	6.498E+18
Oxygen	53.6410	54.4207%	54.4207	3.282E+22
Sodium	0.0774	0.0785%	0.0785	3.295E+19
Magnesium	0.2225	0.2258%	0.2258	8.960E+19
Aluminum	25.7264	26.1004%	26.1004	9.331E+21
Silicon	1.6254	1.6491%	1.6491	5.664E+20
Sulfur	0.2032	0.2061%	0.2061	6.202E+19
Calcium	7.7965	7.9098%	7.9098	1.904E+21
Iron	0.3491	0.3541%	0.3541	6.117E+19
Sum	98.5673	100.0000%	100.0000	8.061E+22

B Nat	4.4982	4.5636%	4.5636	4.071E+21

Table 11, 277-4 Reduce for **NCT** Minimum Density @ Minimum Hydrogen 277-4 Elemental Composition @ 95.39 lb/ft^3 & 25.15% LOD after 250°F for 168 hours

Element	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	2.8137%	2.6840	2.569E+22
B Nat			
^{10}B	0.8682%	0.8282	7.979E+20
^{11}B	3.9160%	3.7354	3.273E+21
Carbon	1.3446%	1.2826	1.031E+21
Nitrogen	0.0099%	0.0094	6.498E+18
Oxygen	52.7581%	50.3252	3.035E+22
Sodium	0.0823%	0.0785	3.295E+19
Magnesium	0.2367%	0.2258	8.960E+19
Aluminum	27.3622%	26.1004	9.331E+21
Silicon	1.7288%	1.6491	5.664E+20
Sulfur	0.2161%	0.2061	6.202E+19
Calcium	8.2922%	7.9098	1.904E+21
Iron	0.3713%	0.3541	6.117E+19
Sum	100.0000%	95.3886	7.320E+22

B Nat	4.7842%	4.5636	4.071E+21

Table 12, 277-4 Reduce for **HAC** Minimum Density @ Minimum Hydrogen 277-4 Elemental Composition @ 95.32 lb/ft^3 & 25.09% LOD after NCT & 320°F for 4 hours

Element	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	2.8073%	2.6758	2.561E+22
B Nat			
^{10}B	0.8689%	0.8282	7.979E+20
^{11}B	3.9190%	3.7354	3.273E+21
Carbon	1.3456%	1.2826	1.031E+21
Nitrogen	0.0099%	0.0094	6.498E+18
Oxygen	52.7305%	50.2605	3.031E+22
Sodium	0.0824%	0.0785	3.295E+19
Magnesium	0.2369%	0.2258	8.960E+19
Aluminum	27.3831%	26.1004	9.331E+21
Silicon	1.7301%	1.6491	5.664E+20
Sulfur	0.2163%	0.2061	6.202E+19
Calcium	8.2986%	7.9098	1.904E+21
Iron	0.3715%	0.3541	6.117E+19
Sum	100.0000%	95.3158	7.308E+22

B Nat	4.7879%	4.5636	4.071E+21

Table 13, 277-4 Reduce for **NCT** Minimum Density @ Minimum Boron 277-4 Elemental Composition @ 94.67 lb/ft^3 & 27.96% LOD after 250°F for 168 hours

Element	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.1284%	2.9617	2.835E+22
B Nat			
^{10}B	0.8356%	0.7911	7.621E+20
^{11}B	3.7688%	3.5680	3.126E+21
Carbon	1.2941%	1.2251	9.848E+20
Nitrogen	0.0095%	0.0090	6.207E+18
Oxygen	54.1129%	51.2291	3.090E+22
Sodium	0.0792%	0.0750	3.147E+19
Magnesium	0.2278%	0.2156	8.559E+19
Aluminum	26.3340%	24.9306	8.913E+21
Silicon	1.6638%	1.5752	5.410E+20
Sulfur	0.2080%	0.1969	5.924E+19
Calcium	7.9806%	7.5553	1.818E+21
Iron	0.3573%	0.3383	5.843E+19
Sum	100.0000%	94.6709	7.563E+22

B Nat	4.6044%	4.3590	3.888E+21

Table 14, 277-4 Reduce for **HAC** Minimum Density @ Minimum Boron 277-4 Elemental Composition @ 94.59 lb/ft^3 & 27.90% LOD after NCT & 320°F for 4 hours

Element	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.1213%	2.9524	2.826E+22
B Nat			
^{10}B	0.8363%	0.7911	7.621E+20
^{11}B	3.7721%	3.5680	3.126E+21
Carbon	1.2952%	1.2251	9.848E+20
Nitrogen	0.0095%	0.0090	6.207E+18
Oxygen	54.0823%	51.1551	3.085E+22
Sodium	0.0793%	0.0750	3.147E+19
Magnesium	0.2280%	0.2156	8.559E+19
Aluminum	26.3572%	24.9306	8.913E+21
Silicon	1.6653%	1.5752	5.410E+20
Sulfur	0.2082%	0.1969	5.924E+19
Calcium	7.9877%	7.5553	1.818E+21
Iron	0.3576%	0.3383	5.843E+19
Sum	100.0000%	94.5876	7.550E+22

B Nat	4.6085%	4.3590	3.888E+21

7.8. Define the Nominal Volumetric Atomic Concentrations

Using nominal mixer weights from Table 8 in Section 7.6 calculate the nominal ^{10}B content at the nominal density and hydration. The following tolerances were taken at the minimum ^{10}B values in ASTM C 750-03 Type 1 at ^{10}B is 19.9±.3 atom% of NatB, Total Boron 81.0 to 76.5, and the mixing weights of 5.88 lb of B_4C to a 102.6323 lb/ft^3 total as shown in Table 4. When these minimum tolerances values are brought to the nominal values one the following differences are found.

NomF ≈Change Atom% × Boron Percentage × Mixer weight changes
NomF ≈ (19.9/19.6) × (78.75/76.5) × (6.4/5.88)
NomF ≈ 1.138

Approximately 13.8% more ^{10}B on the average comparing the values to an exact calculated value is confirmed by comparing the nominal ^{10}B data shown in Table 15 to the data in Table 6.

NomF = Table 15 ^{10}B / Table 6 ^{10}B
NomF = 9.388E+20 / 8.190E+20
NomF = 1.146

On the average 14.6% more ^{10}B is found in the nominal elemental composition.

Table 15, 277-4 At Nominal Density, Boron%, and Mixer Weights
Elemental Composition @ 105 lb/ft^3 & 30.2% LOD

Element	@LOD% (lb/ft^3)	@LOD% (wt%)	@Den & LOD% (lb/ft^3)	N_e (Atoms/cc)
Hydrogen	3.4264	3.3789%	3.5479	3.396E+22
B Nat				
^{10}B	0.9411	0.9280%	0.9744	9.388E+20
^{11}B	4.2445	4.1856%	4.3949	3.851E+21
Carbon	1.2802	1.2624%	1.3255	1.066E+21
Nitrogen	0.0094	0.0093%	0.0098	6.716E+18
Oxygen	55.6706	54.8984%	57.6434	3.476E+22
Sodium	0.0770	0.0760%	0.0798	3.347E+19
Magnesium	0.2215	0.2184%	0.2293	9.103E+19
Aluminum	25.6067	25.2515%	26.5141	9.479E+21
Silicon	1.6179	1.5954%	1.6752	5.754E+20
Sulfur	0.2022	0.1994%	0.2094	6.300E+19
Calcium	7.7605	7.6529%	8.0356	1.934E+21
Iron	0.3484	0.3436%	0.3608	6.232E+19
Sum	101.4065	100.0000%	105.0000	8.682E+22

B Nat	5.1855	5.1136%	5.3693	4.790E+21

8. Conclusion

The dry mix ratios are shown in Table 8 and for 100% dry mix weight and are the following 93.6±0.43% 277-0 Heat Resistant Shielding and 6.4±0.32% Boron Carbide Powder. Once thoroughly dry blended, 27±1% water shall be added to the dry mix weight. Follow the casting specification for final instructions.

The elemental compositional calculations are performed at the minimum ^{10}B level for the compositional purity, isotopic atomic percentage, and scale measurements. The probability of each of these ^{10}B levels being at the minimum limits at the same time is quite remote. As shown in Section 7.8 the minimum limits are over 13 to 14% conservative from the nominal values.

The minimum acceptable casting density at the minimum hydration and ^{10}B levels were subsequently taken at and dehydrated to a worst Normal Conditions of Transport (NCT) and the Hypothetical Accidental Conditions (HAC) temperatures. The thermal stability of the cast 277-4 neutron poison shows little differences between the NCT and the HAC elemental compositions. Therefore, I recommend using the worst case HAC elemental composition for the final Nuclear Criticality Safety Calculations. The largest difference seen is dependent upon the input data. In order to determine the most criticality reactive HAC elemental composition Tables 12 and 14 should both be used to run an infinite array nuclear criticality safety calculation. Upon completion of these calculations the most reactive HAC elemental compositions shall be used for both NCT and HAC calculations.

Appendix 1; Thermo Electron Corp. Heat Resistant Shielding Catalog No. 277 product information sheet 277-103, page 1 of 2

Heat Resistant Shielding
Catalog No. 277

Radiation Measurement & Protection

Thermo ELECTRON CORPORATION

Well suited to attenuate the neutron flux from power reactors by the inclusion of hydrogen and boron in the form of temperature-resistant additives. It incorporates approximately three times as much hydrogen as ordinary concrete, making the material far superior for neutron shielding applications.

- **Low cost material is completely non-combustible**
- **Rugged and easily cast in the field**

General

High temperature resistance is a frequent requirement for power reactor shielding. Type 277 Heat Resistant Shielding is a refractory material designed to retain a significant portion of its shielding properties at temperatures up to 450° F (230° C) . This material will maintain its physical integrity at temperatures up to 1900° F (1038° C). In addition, this low-cost rugged material is completely non-combustible and can be easily cast in the field. Its compressive strength is 1000 psi (90 BAR).

Type 277 is well suited to attenuate the neutron flux from power reactors by the inclusion of hydrogen and boron in the form of temperature-resistant additives. It incorporates approximately three times as much hydrogen as ordinary concrete, making the material far superior for neutron shielding applications. The refractory matrix also provides good resistance to heat.

Type 277 Heat Resistant material has a boron content of 1.56 %. The hydrogen concentration (which moderates fast neutrons) is approximately one-half that of water. For additional technical information on Type 277, including temperature resistance, refer to TD-277-1002.

Type 277 is offered in the form of a dry mix for casting in place, but can also be supplied in pre-cast shapes.It is readily shaped with ordinary tools (e.g., band-saws or drills). Type 277 Dry Mix is available in 100-lb (45.5kg) or larger containers. Approximately 96-lbs. of dry mix are required to obtain one-cubic ft. of cast material. (1.54 kg of dry mix will give one liter). Detailed mixing instructions are provided with each order. Recommended shelf-life under dry storage conditions is six months.

Catalog No. 277 Heat Resistant Shielding is a refractory material designed to retain a significant portion of its shielding properties at temperatures up to 450° F (230° C). This material will maintain its physical integrity at temperatures of up to 1900° F (1038° C).

In addition Catalog No. 277 is a low cost rugged material which is completely non-combustible and can easily be cast in the field. Its compressive strength is 1000 psi (90 BAR).

Catalog No. 277 is well suited to attenuate neutron flux from power reactors by the inclusion of hydrogen and boron (natural isotope distribution) in the form of temperature resistant additives. It incorporates approximately three times as much hydrogen as ordinary concrete, making the material far superior for neutron shielding applications. The refractory matrix also provides good resistance to heat.

For Contact Information visit www.thermo.com/rmp

Appendix 1; Thermo Electron Corp. Heat Resistant Shielding
Catalog No. 277 product information sheet 277-103, page 2 of 2

SPECIFICATIONS

Products Available

Catalog No. 277 is offered in the form of dry mix for casting in place, but can also be supplied in pre-cast shapes and blocks.It is readily shaped with ordinary power tools (e.g. band-saws or drills).

Catalog No. 277 Dry Mix is available in 300-lb (136 kg) containers. Approximately 96-lbs of dry mix are required to obtain one-cubic foot of cast material (1.54 kg of dry mix will give one liter). Water 27 PPH, parts of dry mix (by weight).

Recommended shelf life for Catalog No. 277 under dry-storage conditions is 6 months.

Composition Data

Active Components:

Hydrogen atom density / cm^3:	3.4×10^{22}/cc
Natural isotope distribution:	99.98% $_1H$
Boron atom density / cm^3:	1.43×10^{21}
Natural isotope distribution:	19.6% $_{10}B$ and 80.4% $_{11}B$
Weight percent of all isotopes of boron:	1.56%
Total Density:	1.68 g / cc

Radiation Properties

Macroscopic thermal neutron cross section:	1.1 cm^{-1}
Gamma resistance:	1×10^{11} rads
Neutron resistance:	5×10^{19} n / cm^2

Physical Properties

Appearance and Odor:

State	Powder
Color	Light Gray
Odor	no odor

Mechanical Properties

Machining of 277:	Fair, can be saw cut and drilled
Hardness:	N/A
Tensile Strength (ASTM D368):	100 psi (kg/m^2)
Compressive Strength:	1000 psi (kg/m^2)

Thermal Properties

Recommended Temperature Limit:	350°F
Melting Point:	N/A
Boiling Point:	N/A
Coefficient of Thermal Conductivity:	1.24×10^{-3} cal-cm/sec cm^2 °C – 0.3 BTU · ft/hr ft^2 °F
Heat Capacity:	0.22 cal/g °C
Cubical Coefficient of Expansion:	8×10^{-6} cm^3/cm^3 °C – 1.4×10^{-5} in^3/in^3 °F
Linear Coefficient of Expansion	N/A
Vapor Pressure (mm Hg):	N/A
Vapor Density (Air – 1):	N/A
Evaporation Rate (ether–1):	N/A
Percent Volatile by Volume:	N/A
Specific Gravity (H_2O – 1):	1.68 g/cm^3

Chemical Properties

Chemical Name & Synonyms:	Borated Hydrogenated Casting Mix
Trade Name & Synonyms:	Catalog No. 277
Chemical Family:	Calcium salts, boron, and hydrogen containing compounds
Formula:	Proprietary
Solubility in Water:	Negligible

Reactivity Data

Reactive Materials

Reactive Acids:	N/A
Reactive Bases:	N/A
Reactive Metals and Metal Compounds:	N/A
Reactive Oxidizing Agents:	N/A
Reactive Reducing Agents:	N/A

Material Incompatibility

Materials to Avoid:	N/A
Hazardous Decomposition Products:	
Solid	None
Liquid	None
Gas	None
Hazardous Polymerization:	Will Not Occur

For more information see: TD-277-001

Radiation Measurement & Protection

Thermo ELECTRON CORPORATION

277-103

Appendix 2; Thermo Electron Corp. Heat Resistant Shielding Catalog No. 277 Typical Elemental Analysis Without Boron, EA-277, May 1988.

EA-277
Without Boron
May, 1988

TYPICAL ELEMENTAL ANALYSIS

CATALOG NO. 277 - HEAT RESISTANT SHIELDING

Element	Weight Percent
O	59.14%
Al	26.59
Ca	8.04
H	3.73
Si	1.68
Fe	0.30
Mg	0.23
S	0.21
Na	0.08
Total	100.00%

PROPERTIES

Density = 1.61 g/cc (101 lbs/cu ft)

Hydrogen Atoms per cc = 3.59×10^{22}

Macroscopic Thermal Neutron Cross Section: Σ = $0.01 cm^{-1}$

Recommended Temperature Limit = 350°F (177°C)

Machinability: Fair; can be saw-cut and drilled

Thermal Conductivity, K = 1.24×10^{-3} cal-cm/(sec)(cm)²(°C)

Specific Heat = 0.22 cal/gpC

Coefficient of Theraml Expansion = 1.4×10^{-5}cm per cm per °C

Compressive Strength = 1400 psi

Tensile Strength = 95 psi

Radiation Resistance, gammas: 1×10^{11} Rads

Radiation Resistance, neutrons: 1×10^{21} n/cm²

THERMAL TESTS AND CHARACTERISTICS

These tests have not been performed on this Type 277 without boron. We have examined each test separately, and we feel confident that the results of all these tests and that the characteristics of the material would be essentially the same as for Type 277 with boron.

APPENDIX 1.4.10

PYROPHORICITY OF URANIUM METAL

Prepared by: Russell W. Schmidt
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November 2006
Revised June 2007

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November 2006
Re-reviewed June 2007

APPENDIX 1.4.10

PYROPHORICITY OF URANIUM METAL

I. Introduction

The ES-3100 is a new shipping container designed for safe and efficient transportation of highly enriched uranium in a wide range of material forms. The ES-3100 has been certified for use with a variety of contents, including enriched uranium metal and alloy. However, the current size limitations on uranium contents in the form of broken metal are unnecessarily restrictive. The size limits exist because under certain conditions uranium metal and some uranium alloys are pyrophoric – they have the potential to spontaneously ignite. The size restrictions are intended to eliminate the possibility of spontaneous ignition during transport.

The purpose of this analysis is to evaluate the potential for uranium metal pieces to spontaneously ignite under the conditions expected for shipment in the ES-3100 shipping container, and to identify limits on the uranium metal content that will prevent spontaneous ignition during transport, while still allowing a high degree of flexibility and utility.

It is important to remember that the content limits developed for the ES-3100 must be implemented in the field. Therefore the criteria derived from this evaluation must be simple, robust, and readily applied in all of the facilities using this package.

This evaluation does not include new laboratory tests of uranium metal ignition parameters. Such tests have been performed and well documented in the past. This evaluation draws on the extensive body of existing data and proven storage and transport practice to identify the bounds within which uranium metal and alloys can be safely transported in the ES-3100 shipping container.

II. Proposed Definition of Pyrophoricity

The Certificate of Compliance (CoC), gives the definition of broken metal in paragraph 5.(b)(1)(ii), as follows:

> *For metal or alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must have a mass not less than 50 g, whichever is most restrictive. Powders, foils, turnings, wires, and incidental small particles are not permitted, unless they are restricted to not more than 1 percent by weight of the content per convenience can, and they are either in a sealed, inerted container or are stabilized to an oxide prior to shipment.*

It is suggested that the definition of broken metal in paragraph 5.(b)(1)(ii) be revised to the following:

> *For metal and alloy defined as broken metal, mass limits are specified in Table 2. Uranium metal and alloy pieces must have a surface-area-to-mass ratio of not greater than 1 cm²/g or must not pass freely through a 3/8-inch (0.0095m) mesh sieve. Particles and small shapes that do not pass this size restriction, as well as powders, foils, turnings, and wires, are not permitted, unless they are either in a sealed container under an inert cover gas.*

III. Rational for Proposed Changes

The proposed text makes the following changes:

- The 50 g minimum piece size is eliminated;
- A 3/8-in. mesh limit is added;
- The phrase "whichever is most restrictive" is deleted;
- Remove oxidation as a treatment for pyrophoric uranium, in this context
- The 1% limit on inerted material is eliminated.

The 1 cm^2/g maximum specific surface area limit is the most significant limit in the original text, and that limit is retained unchanged. Specific surface area is the most significant parameter in determining if a given piece of uranium is at risk of spontaneous ignition under a given set of conditions, and therefore it is appropriate that this restriction should control any other restrictions to the package contents. The discussion section below will demonstrate that the 1 cm^2/g maximum allowable specific surface area is adequate to prevent spontaneous ignition in the ES-3100.

The 50 g minimum piece size is overly restrictive and is inconsistent with the 1 cm^2/g upper limit on specific surface area. Smooth uranium metal pieces can have a mass of less than 0.5 g and still have a specific surface area less than 1 cm^2/g (see example 1). This makes the 50 g limit two orders of magnitude too large. The 50 g limit is nearly an order of magnitude too large even considering metal pieces with the rough surface of broken metal instead of a smooth cast or polished surface.

Example 1.

Consider a smooth uranium metal sphere with a diameter of 0.32 cm (0.126 in.).
The radius of the sphere is 0.16 cm. The density of uranium metal is 19 g/cm^3.
The volume is $V = (4/3) \cdot Pi \cdot r^3 = (4/3) \cdot Pi \cdot (0.16)^3 = 0.01716\ cm^3$
The mass is $M = Density \cdot V = 19\ g/cm^3 \cdot 0.01716\ cm^3 = 0.3260\ g$
The surface area is $A = 4 \cdot Pi \cdot r^2 = 4 \cdot Pi \cdot (0.16)^2 = 0.3217\ cm^2$
The specific surface area is $SA = A/M = 0.3217\ cm^2 / 0.3260\ g = 0.9868\ cm^2/g$
This specific surface area is just within the 1 cm^2/g upper limit.

If instead of a smooth surface the sphere has a rough surface characteristic of broken uranium metal, a larger size is needed to ensure that the 1 cm^2/g limit is maintained. For a roughness factor of three (meaning that the rough surface has an actual surface area that is three times the surface area calculated from the radius), the radius would need to be three times the above example to give the same specific area. In this case:
$r = 3*0.16\ cm = 0.48\ cm$; $V = (4/3) \cdot Pi \cdot (0.48)^3 = 0.463\ cm^3$;
$M = 19\ g/cm^3 \cdot 0.463\ cm^3 = 8.802\ g$; $A = 4 \cdot Pi \cdot (0.48)^2 \cdot 3$ (roughness factor) $= 8.686\ cm^2$
And so the specific surface area is $8.686\ cm^2/8.802g = 0.9868\ cm^2/g$ as above.

Depending on the surface roughness, a sphere with a mass between 0.33 and 8.8 grams will meet the 1 cm^2/g specific surface area limit.

The 1 cm^2/g specific surface area limit controls the parameter that is most important in terms of preventing spontaneous ignition, but it is not easy to measure or to use in the field. A mass limit (similar to the 50 g limit in the existing certificate, but more consistent with the 1 cm^2/g specific area limit) could be used, but it is very time-consuming to weigh every piece of metal in a package. An approach that is both effective at enforcing the 1 cm^2/g specific surface area limit and quick and easy to use in the field is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

As demonstrated in example 1, rough-surfaced spheres 3/8 in. (0.95 cm) in diameter meet the 1 cm^2/g specific surface area limit (a smooth-surfaced sphere of this size has a specific surface area of 0.33 cm^2/g). Therefore, a sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere.

The phrase "whichever is most restrictive" has been deleted from the proposed text since the sieve test has been sized to effectively enforce the 1 cm^2/g specific surface area limit.

The option of converting pyrophoric uranium to an oxide is removed, since metals need to be shipped as metals for maximum usefulness at the receiver site. In addition, if oxides are produced, packing limits for oxides have been explicitly given in the certificate of compliance.

The final change in the proposed text is to eliminate the 1% of content weight limit on inerted material. This limit is unnecessary for uranium metal sealed in a container containing an inert atmosphere. If the metal has been sealed in a container containing an inert atmosphere, there is no oxygen available to the metal and therefore no chance of combustion.

Uranium metal packaged for transport in the ES-3100 is first placed inside a convenience can or other container. These cans are then placed into the ES-3100 containment vessel (CV). The convenience cans will displace most of the oxygen from the containment vessel, leaving only enough to react with a few grams of metal. If a sealed container containing an inert atmosphere somehow came open in transport (an unlikely scenario given the very limited amount of movement possible inside a properly loaded containment vessel), this small amount of oxygen is not enough to support spontaneous ignition. The containment vessel has been shown to retain its structural integrity and remain leak tight under hypothetical accident conditions, so no additional oxygen can enter.

IV. Discussion

In his 1995 review,[1] Terry Totemeier explains pyrophoricity this way: "Pyrophoricity refers to the tendency of certain metals to ignite and burn in a self-sustaining oxidation reaction. The pyrophoric nature of metals is usually defined in terms of an ignition temperature, which is the temperature at which a metal will ignite and burn in a self-sustained fashion for a given set of conditions." ASTM C-1454[2] defines pyrophoric as "capable of igniting spontaneously under temperature, chemical, or physical/mechanical conditions specific to the storage, handling, or transportation environment".

This evaluation will demonstrate that uranium metal with a specific surface area of 1 cm^2/g will not spontaneously ignite under the conditions existing in the ES-3100 during packaging and transport.

The primary factors determining if the conditions for spontaneous ignition exist are specific surface area and temperature. Totemeier explains, "Because oxidation is a surface reaction, the amount of area available for reaction is a critical factor in the determination of the heat generated in oxidation. Specific area is the best parameter to describe the effect of area, as it also accounts for the amount of material not reacting which can serve as a heat sink." Temperature is critical because the amount of heat generated by the reaction is a function of the reaction rate, which is in turn a function of the temperature. Higher temperatures give higher reaction rates.

An additional safety factor in the case of the ES-3100 is the small amount of oxygen available in the sealed inner containment vessel. This serves to limit the total amount of uranium that can oxidize, and therefore prevents any potential heat build-up from reaching the ignition point of uranium metal.

Ignition Temperature and Transport Conditions
In figures 4 and 5 of his review, Totemeier plots two separate tests of uranium ignition temperatures as a function of specific surface area. For a specific surface area of 1 cm^2/g these two plots give values of 390°C (663 K)[a] and 340°C (613 K), respectively. Using the lower value and rounding down gives a conservative value of 600 K for the ignition temperature of uranium metal in the ES-3100.

The ES-3100 thermal analysis determined that the temperature at the containment vessel wall would not exceed 190°F (361 K) for normal conditions of transport (NCT) and 255°F (397 K) for hypothetical accident conditions (HAC). These values, particularly the HAC temperature, are very conservative. The actual results from six separate package tests showed that the CV wall temperature was typically around 210 °F (372 K), with the highest recorded value of 241 °F (389 K). Note that all of these temperatures are well below the 600 K ignition temperature of the uranium metal contents.

Maximum Temperature from Oxidation – Basic Equations
Uranium metal readily reacts with oxygen to form uranium dioxide (UO_2). This reaction is exothermic. The heat released by the reaction warms the uranium metal, increasing the reaction rate. Under normal conditions for storage and transport, the reaction rate is slow enough that the small amount of heat generated by the reaction is lost to the environment, and a stable steady-state is achieved. If the reaction rate is fast enough, and the metal is relatively well insulated, the temperature of the uranium metal can build, slowly at first but at an increasing rate, until the ignition temperature is reached and the metal ignites and burns.

The task at hand is to evaluate the balance between heat generation and heat loss in the ES-3100 under hypothetical accident conditions to verify that a stable steady state is reached, and that the steady-state condition is safely below the ignition point of uranium metal. A recent paper by Epstein, Malinovic, and Plys[3] lays out a useful approach, which will be followed here without the approximations used in their paper.

For uranium metal packed in cylindrical cans, the generation of heat throughout the can and the associated transfer of heat to the can wall is mathematically identical to the generation of heat within a wire due to electrical resistance. In their text "Transport Phenomena"[4] Bird, Stewart & Lightfoot develop the desired relation (equation 9.2-14):

$$T_{center} - T_{wall} = (S \cdot R^2) / (4 \cdot K_{th}) \qquad \text{(Equation 1)}$$

where

[a] The curve in Totemeier figure 4 is discontinuous, with a transition from a lower curve to an upper curve shown at a specific surface area of 6 cm^2/g. At a specific surface area of 1 cm^2/g the upper curve would give an ignition temperature of 550°C, while extrapolation of the lower curve gives 390°C. The original reference from which Totemeier drew figure 4 explains that the transition from the lower curve to the upper curve is influenced by many factors, including the metallurgy of the uranium, any alloying metals or impurities, and the oxygen content of the gas involved. Therefore this analysis uses the lower curve value of 390°C.

Tcenter is the temperature at the center of the can (K)
Twall is the temperature at the can wall (K)
S is the heat production per unit volume (W/cm³)
R is the radius of the can (cm)
Kth is the thermal conductivity of the uranium contents (W/cm K)

The heat production per unit volume is a function of the reaction rate and the heat of reaction. Since the oxidation reaction occurs at the surface of the uranium, the reaction rate is typically stated as a mass reacted per second per unit area. The specific surface area, the uranium metal density, and the packing density are applied to convert the rate per unit uranium surface area to a rate per unit can volume. The result is:

$$S = Rho \bullet Phi \bullet SArea \bullet dHrxn \bullet RxnRate \qquad \text{(Equation 2)}$$

where
Rho is the density of the uranium metal (g/cm³)
Phi is the packing density of the uranium in the can (cm³ U/cm³ can volume)
SArea is the specific surface area of the uranium (cm²/g)
dHrxn is the heat of reaction (J/g uranium)
RxnRate is the reaction rate (g uranium / (s • cm²))

The reaction rate of uranium metal with oxygen has been evaluated by many researchers over the years. The general form of the rate equation used is:

$$RxnRate = K0 \bullet P^{n} \bullet e^{(-Te/T)} \qquad \text{(Equation 3)}$$

where
K0 is the reaction rate coefficient (g uranium / (s • cm²))
P is the partial pressure of water vapor (kPa)
n is the exponential coefficient on the partial pressure of water vapor
Te is the activation energy (K)
T is the temperature of the reactants (K)

For the case at hand, the temperature of the reactants is the highest at the can center (Tcenter) and the lowest at the can wall (Twall). The average temperature of the reactants is midway between these two values. For conservatism the reaction rate of the entire contents is evaluated at the maximum temperature, which occurs at the center of the can (Tcenter). This analysis considers heat transfer only through the can walls, and ignores heat transfer through the top and bottom of the can. This is also a conservative assumption.

Equations 1, 2, and 3 are combined to yield:

$$Tcenter - Twall = (R^2 \bullet Rho \bullet Phi \bullet SArea \bullet dHrxn \bullet K0 \bullet P^{n} \bullet e^{(-Te/Tcenter)}) / (4 \bullet Kth) \qquad \textbf{(Equation 4)}$$

Note that Kth is a property of the can contents (that is, for the bed of uranium metal particles with air in between), and not a property of solid uranium metal. The thermal conductivity of uranium metal is much higher than the thermal conductivity of a bed of uranium metal pieces.

P is the partial pressure of H_2O present in the containment vessel at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 and 100%

relative humidity, which yields a water vapor pressure of P0. When the temperature in the containment vessel increases the partial pressure of water vapor increases according to the ideal gas law, which in this case reduces to:

$$P = P0 \bullet (Tcenter/T0) \qquad \text{(Equation 5)}$$

In this evaluation, the maximum possible rate of heat generation due to the oxidation of the uranium metal is also of interest since this heat must be carried away by the package, even at HAC. The maximum rate of heat generation is the heat generated by the oxidation of uranium metal at the highest temperature reached during HAC, assuming the maximum allowable load of uranium metal. This is:

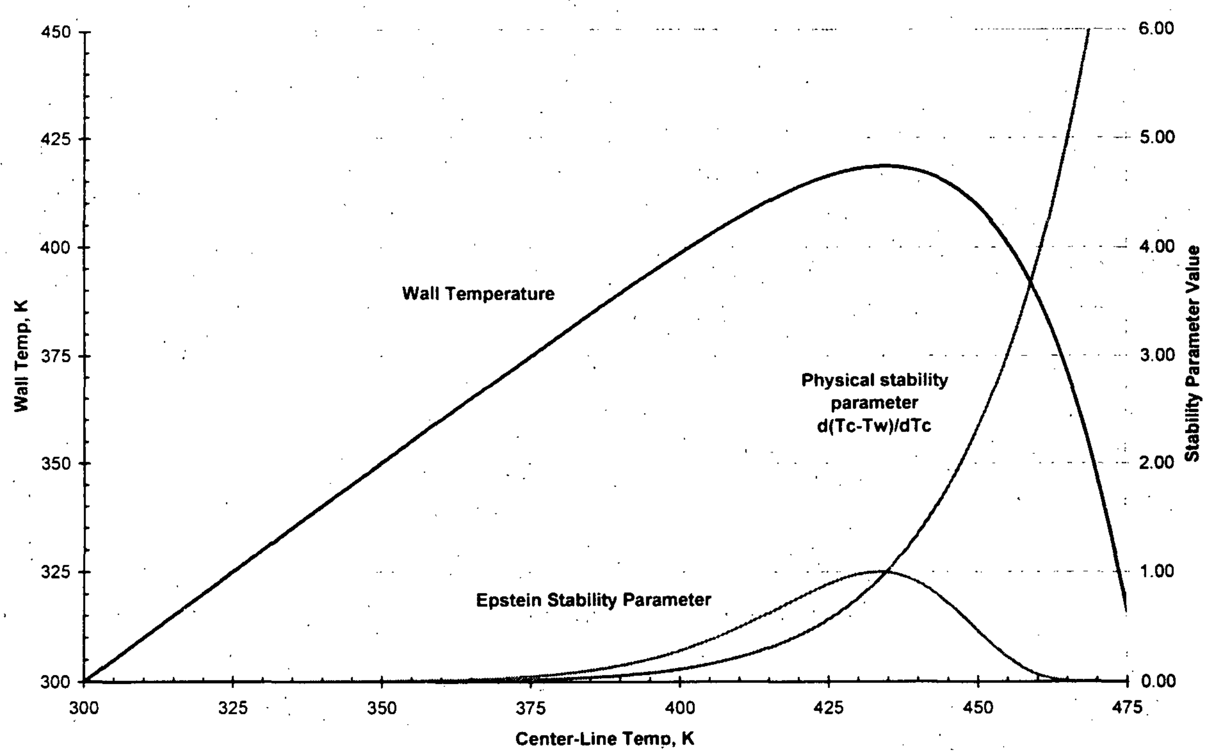
$$Qmax = Mmax \bullet SArea \bullet dHrxn \bullet K0 \bullet P^n \bullet e^{(-Te/Tcenter)} \qquad \text{(Equation 6)}$$

where
Qmax = the maximum rate of heat generation (W)
Mmax = the maximum uranium metal loading (g)

Evaluation of Thermal Stability
Equation 4 provides the means to evaluate the maximum temperature reached in the uranium metal. It does not by itself validate the stability of the system. This system does present a simple means to evaluate stability – both numerical stability and more importantly physical stability (meaning that the temperature cannot build to spontaneous ignition).

Solving equation 4 for Twall over a range of Tcenter values and plotting the results produces figure 1:

Figure 1. Thermal Stability of Uranium Metal Package



The wall temperature calculated from equation 4 and plotted here is the temperature needed in order to provide enough heat transfer to maintain the given center-line temperature. The wall temperature initially tracks the center-line temperature – the rate of heat generation is low, so a very small temperature difference is sufficient to remove that heat. As the center-line temperature (and therefore the amount of heat generated) increases, the temperature difference needed to keep the center-line temperature steady at the given value increases exponentially. At some point (about 435 K in figure 1) the required temperature difference gets so large that the wall temperature would have to decrease in order to maintain a stable center-line temperature. In an actual package there is no cooling mechanism to do this, and once the center-line temperature exceeds this point the amount of heat generated will exceed the ability to carry off that heat, and the center-line temperature will increase until either the reaction runs out of oxygen or the ignition point is reached. The point at which the required wall temperature stops increasing, marks the maximum stable center-line temperature for the package. The required wall temperature stops increasing at the point where the rate of increase in the needed temperature difference (d(Tcenter-Twall)) equals the rate of increase of the center-line temperature (dTcenter). Stated mathematically, when d(Tcenter-Twall)/dTcenter is less than 1 the required Twall increases along with Tcenter, and stability is maintained. When d(Tcenter-Twall)/dTcenter is greater than 1 Twall would have to drop to maintain stability as Tcenter increases. Since this is not possible in a real package, the temperature in the package would steadily increase to either ignition or consumption of all available oxygen. The value of d(Tcenter-Twall)/dTcenter = 1 marks the maximum stable point for a given package.

Equation 4 is

$$Tcenter - Twall = (R^2 \cdot Rho \cdot Phi \cdot SArea \cdot dHrxn \cdot K0 \cdot P^n \cdot e^{(-Te/Tcenter)}) / (4 \cdot Kth)$$

Taking the first derivative of this equation with respect to Tcenter yields an equation for the stability parameter derived above:

$$d(Tcenter\text{-}Twall)/dTcenter = (Tcenter\text{-}Twall) \cdot Te/Tcenter^2 \qquad \text{(Equation 7)}$$

The thermal stability of the system is maintained as long as (Tcenter-Twall) • $Te/Tcenter^2 \leq 1$. This parameter is equivalent to the stability parameter "B" developed in Epstein et al, without the simplifying assumptions made in that paper. The value of d(Tcenter-Twall)/dTcenter is plotted in Figure 1, along with the Epstein "B" parameter.

Input Parameters
The key values used to evaluate equations 4, 5, 6, and 7 are shown in Table 1.

Table 1. Key input parameters

Parameter	Value	Units
R	5.27	cm
Rho	19	g/cm^3
Phi	0.26	cm^3/cm^3
SArea	1	cm^2/g
dHrxn	4559	J/g Uranium
K0	76086	$gU/(s \cdot cm^2)$
P0	3.53	kPa
T0	300	K
n	0.3	
Te	11490	K
Kth	0.004	W/(cm • K)

The sources of these parameters are:

R is the inside radius of a convenience can. The typical can used has an outside diameter of 4.25 in. and an inside diameter of 4.15 in. (10.54 cm).

Rho is the density of uranium metal.

Phi is the packing density of uranium metal when packed into the convenience cans. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 cm³. This yields a packing density of 0.26 cm³/cm³. The effects of variations on this value are discussed below.

SArea is the specific surface area, which is limited by the package certification to 1 cm²/g.

dHrxn is the heat of reaction, on a uranium basis. This value came from Totemeier, page 17 (1089 cal/gU = 4559 J/gU).

K0, n, and Te are parameters for the reaction rate equation. As noted above, a number of researchers have analyzed the reaction rate of uranium metal with various combinations of oxygen and water vapor. Numerous models have been developed from this data. This analysis used the published model that best fit the conditions present. Many of the published rate models are only valid up to 100 to 130°C. This evaluation requires evaluation beyond 140°C. Many of the models are for either pure oxygen or pure water vapor. McGillivray[5] notes that the reaction rate at a given temperature varies with both the oxygen concentration and the partial pressure of water vapor. The published model that best matches the conditions of this evaluation (reaction in air at temperatures exceeding 140°C, with a small water vapor partial pressure) is the Pearce model (Pearce, < 100% RH, in Air, T < 192°C) as reported in the Epstein paper.

P0 and T0 are used to calculate P, the partial pressure of H_2O vapor present in the containment vessel at the center-line temperature. This value is calculated by assuming that the ES-3100 was loaded at ambient conditions of T0 = 300 K (80°F) and 100% relative humidity. P0 is therefore the vapor pressure of water at 300K, which is P0 = 3.53 kPa. When the temperature in the containment vessel increases, the partial pressure of water vapor increases according to equation 5.

Kth is the thermal conductivity of the uranium particle bed. The value here was taken from Epstein et al, page 6. Because of the air-filled void spaces, the bed thermal conductivity is much lower than the uranium metal value of 0.3 W/(cm • K).

Results

The set of equations (4, 5, 6, and 7) was evaluated using a commercial software package named Tk!Solver, which has the advantage of being able to automatically iterate to solutions as needed. This is necessary when solving equation 4 for a fixed wall temperature to determine Tcenter. Attachment 1 shows the rules, input and output for the TK!Solver model for the HAC and NCT cases.

The hypothetical accident condition evaluation gave a maximum containment vessel (CV) temperature (Twall) of 255°F (397 K). Evaluating equations 4 through 7 for these conditions yields a Tcenter of 398.4 K (257.5°F), with a maximum heat output (assuming a full load of 36 kgU) of 5.9 Watts, and a stability parameter d(Tcenter-Twall)/dTcenter of 0.102, well below the critical value of 1.0.

The 255°F HAC temperature was based on a uranium heat generation of 0.4 W. The 5.9 W maximum heat generated from the oxidation reaction under those conditions would heat the CV wall above that temperature. The thermal analysis evaluated the HAC for heat generation rates of 20 W and 30 W as well as the 0.4 W standard value. Table 3.7 in the thermal analysis shows that for an assumed 20 W heat generation in the uranium metal contents, the peak CV wall temperature is 277 °F (409.3 K). Using this value ensures that the heat transfer from the uranium contents to the CV wall and to the rest of the package is conservatively addressed.

For the revised HAC wall temperature of 277 °F (409.3 K), equations 4 through 7 yield the following results:

Tcenter = 413.3 K (284.4 °F) (well below the ignition temperature of 600 K)
MaxQ = 17.0 Watts (below the 20W assumption)
d(Tcenter-Twall)/dTcenter = 0.272 (well below the critical value of 1.0)

At the NCT wall temperature of 190°F (360.9 K) the results are:

Tcenter = 361.0 K (190.1 °F) (well below the ignition temperature of 600 K)
MaxQ = 0.289 Watts (below the 0.4W assumption)
d(Tcenter-Twall)/dTcenter = 0.006 (well below the critical value of 1.0)

These values clearly show that uranium metal with a specific surface area of no more than 1 cm^2/g will not spontaneously ignite under any anticipated transport conditions.

Variation in Input Packing Density

The density with which uranium metal is packed into the convenience cans limits the surface area available to oxidize. Operator experience at Y-12 is that a maximum of 5 kg U of broken metal will fit into a 4.25-in. OD by 4.875-in. high can, which has an internal volume of 1000 cm^3. This yields a packing density of 0.26 cm^3/cm^3.

A search of the literature on packing densities reveals a lot of work on smooth spheres, and very little on anything else. Scott and Kilgour[6] experimented with packing smooth steel spheres in cylinders, and reported a maximum packing density of 0.6366 after extensive vibration to compact the steel spheres as much as possible. The steel balls used in this experiment had a coefficient of friction of 0.2, well below the value for smooth uranium metal of 1.0. Subsequent analysis by Kong and Lannutti[7] considering the effects of friction between particles gives packing fractions in the range of 0.41 to 0.46, with higher friction coefficients producing lower packing fractions.

The broken metal routinely packed at Y-12 consists of large, rough, irregular pieces. The reported packing density of 0.26 for this material is consistent with the literature reviewed, particularly Kong and Lannutti. Therefore the value of 0.26 was used as the base value in the analyses reported above.

To bound the metal contents of the ES-3100 two additional cases have been analyzed under hypothetical accident conditions: rough broken metal at a packing density of 0.46 (the upper end of the range reported by Kong & Lannutti); and smooth cast spheres at a packing density of 0.64 (consistent with Scott & Kilgour).

For rough broken metal at a packing density of 0.46 the maximum center temperature at HAC was 422 K, well below the ignition temperature of 600 K. For smooth cast 3/8" spheres at a packing density of 0.64 the maximum center temperature at HAC was 412 K, well below the ignition temperature of 600 K.

Oxygen Limitation in the Containment Vessel

The analysis above placed no restriction on the amount of oxygen available to react with the uranium metal contents. In reality, the ES-3100 containment vessel has a finite volume, which restricts the amount of oxygen available for reaction.

The CV is a cylinder with inside dimensions of 31.00 in. (78.74 cm) tall and 5.06 in. (12.85 cm) in diameter. This produces a volume of 10,215 cm^3, or 10.215 liters. At ambient conditions of 300 K (80.3°F) and 100% relative humidity, 10.215 liters of humid air contains 2.78 g of oxygen from the air, and another 0.23 grams of oxygen in the H_2O. These 3.01 grams of oxygen can react with 22.40 g of uranium metal. This is 0.06% of the ES-3100's capacity.

A mass of 22.4 g of U metal when reacted with 3.01 g of oxygen will produce a maximum total heat output of 102 kJ (96.8 BTU), spread out over the time required for the reaction to take place. This total amount of oxygen could sustain the NCT maximum heat output of 0.289 W for 4.1 days, or the HAC peak heat output for 1.7 hours. If somehow released all at once, the 102 kJ would only raise the temperature of 36 kg of uranium by 24.5 K. More realistically, as shown by the calculations above, any reaction will be slow, with enough time for the heat generated to flow to the CV and the rest of the package.

The ES-3100 CV is 15.1 kg of stainless steel, with a heat capacity of 0.515 J/(g •K). The 102 kJ maximum produced by the oxidation reaction could only raise the temperature of the CV (ignoring contents) by 13.1 K. This heat sink, plus the heat sinks offered by the CV contents, ensures that the oxidation reaction will not be able to build to the 600 K ignition temperature required for spontaneous ignition.

In practice there will less than 3 g of oxygen available to react with the uranium metal inside the closed CV. A full load of uranium will, by itself, displace nearly 20% of the air in the CV. The convenience cans, spacer cans, and other packing materials will displace even more air, further reducing the amount of uranium that could possibly react. Also, the uranium metal is packed inside closed convenience cans. These cans limit the oxygen available to react with the contents to the oxygen in the convenience can itself. Finally, part of the available oxygen will react with the uranium before the peak HAC conditions are reached. Figure 22b in section 3 shows that it will take about 4 hours for the CV wall to reach the maximum temperature in the HAC fire. During this four-hour temperature ramp-up 0.9 grams of oxygen would be consumed by reaction with the uranium, leaving only 2.1 grams available to react once the HAC temperature was reached. Even if the uranium surface area was uncontrolled, lack of oxygen would snuff out any increase in the uranium reaction rate before it could reach the ignition point.

Specific Surface Area Implementation via Sieve

As noted above, the 1 cm^2/g specific surface area limit is not easy to measure or to use in the field. A screening method that is simple and easy to use in the field will reduce the potential for packaging mistakes. The recommended approach is to separate large pieces from small ones in a sieve. The recommended text stipulates a 3/8-in. mesh sieve to quickly remove small particles (with a large specific surface area) from large particles which have a small specific surface area.

Example 1 above showed that the minimum size of a metal sphere meeting the 1 cm^2/g specific surface area limit varies with the degree of surface roughness. In example 1 a smooth sphere 1/8 inch in diameter and a rough sphere 3/8 inch in diameter both had specific surface areas just below the 1 cm^2/g limit. The 3/8-in. mesh is stipulated in the recommended text in order to accommodate both smooth and rough metal.

The actual metal contents of the ES-3100 will include both smooth-surfaced and rough-surfaced metal. The smooth-surfaced items include a variety of cast and machined shapes. The rough-surfaced items are "broken metal" – large castings that have been fractured into smaller pieces. These broken metal pieces will typically have two or three cast surfaces with the remaining 3 or 4 surfaces of fractured metal.

The 3/8-inch mesh recommendation is based on a surface roughness factor of three, meaning that the rough surface has an actual surface area available to react with oxygen that is three times that of a smooth-surface of the same gross dimensions. This roughness factor of three was derived from an evaluation of fracture surfaces for cast uranium metal. Roughness factors ranged from 1.1 to 2.7, with a mean value of 2.0. A roughness factor of three was selected to bound the highest value observed. The 3/8 inch mesh screening is therefore suitable for metal that is fractured on all surfaces. Since as noted above even broken metal will have several smooth faces, the 3/8-inch mesh screening should be quite conservative.

As demonstrated above, a rough-surfaced sphere which does not pass freely through the 3/8-in. mesh sieve will meet the 1 cm^2/g specific surface area limit. Other simple shapes such as cubes and rods are also effectively controlled by the 3/8-in. sieve. Foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packaged in an inert atmosphere. Attachment 2 shows the dimensions of a variety of shapes that have a specific surface area of 1 cm^2/g. All of these items will fall through a 3/8-in. sieve, demonstrating that the sieve will effectively enforce the 1 cm^2/g specific surface area limit.

Most foils and wires will not fall through a sieve of any reasonable size. The current 50 g test would likewise not reliably exclude these materials, which is why foils, turnings, and wires are explicitly forbidden in both the current and proposed text, unless they are packed in an inert atmosphere. Operator training will be required under either the current or the proposed text to ensure that these items are properly packaged.

Operator Training

As part of the transition to using the new shipping container, training materials are being prepared to instruct the field operations personnel on the proper way to use the ES-3100. As noted above, the training for the operators packing uranium metal into the convenience cans for shipment in the ES-3100 will be important in ensuring that potentially pyrophoric materials are properly categorized and inerted as necessary. This training will cover the following points:

- All metal pieces must be evaluated to ensure that their smallest dimension is larger than the 3/8 inch mesh size.
    - Single solid-metal pieces that are clearly larger than the 3/8-inch mesh in every dimension do not require sieving.
    - Items which are obviously unacceptable, such as foils, wires, and turnings, may be removed before the sieving
    - Any item that is not obviously larger than the 3/8-inch mesh in every dimension and which has not been rejected must be sieved.
    - Any item that falls through the sieve must be rejected.
- Operators need to be alert to items which may not fall through the sieve but which are too small:
    - Long, thin shapes such as wires and turnings may not fall through the sieve when shaken. If the wire or turning could be picked up and poked through the mesh it must be rejected, even if it did not fall through unassisted.
    - Wires or turnings may form a tangled ball which will not fall through. The above criterion applies: if the wire or turning could be separated and poked through the mesh it must be rejected.

- No distinction is made between wires and rods – if the item could be picked up and poked through the mesh it must be rejected.
  - Foils, thin chips or shards - any item less than 1/8 inch thick – must be rejected.
  - Metal showing visible moisture or signs of having been stored in water must be rejected.
- Rejected items must be separated for proper handling:
  - Rejected items can be shipped if packed under an inert cover gas.
  - An acceptable cover gas must be high-purity (≥ 99.997%) and dry (≤ 5 ppm moisture).

V. Conclusion

The evaluations performed show that uranium metal conforming to the 1 cm^2/g limit on specific surface area will not spontaneously ignite under any anticipated transport conditions. Spontaneous ignition is independently prevented by both the 1 cm^2/g limit on the uranium metal and by the limited amount of oxygen available in the sealed ES-3100 containment vessel.

The 3/8-in. sieve specified in the revised text effectively applies the 1 cm^2/g specific surface area limit to broken uranium metal in a manner that is quick and easy to use in the field.

Attachment 1 TK!Solver Model and Results

Rules

```
Tcenter-Twall=((R^2*rho*phi*SArea*dHrxn*K0*P^n)/(4*Kth))*exp(-Te/Tcenter)
P=P0*(Tcenter/T0)
Deriv=(Tcenter-Twall)*Te/Tcenter^2
HRate=SArea*dHrxn*K0*P^n*exp(-Te/Tcenter)
MaxQ=HRate*MaxM
RRate=SArea*MaxM*K0*P^n*exp(-Te/Tcenter)
ORate=RRate*32/238
OTime=MaxO/ORate
```

HAC - 277 °F Wall Temperature

Input	Name	Output	Unit	Comment
	Tcenter	413.348	K	Temperature at the center of the can
409.3	Twall		K	Temp at the can wall
	HRate	.000472	W/gU	Rate of heat production (w/unlimited O2)
	MaxQ	16.9945	W	Maximum heat production (from max KgU)
36000	MaxM		gU	Maximum ES-3100 contents
3.01	MaxO		gO	Maximum ES-3100 Oxygen Content
	RRate	.003728	gU/s	Reaction Rate at given Conditions
	ORate	.000501	gO/s	Oxygen Use rate at given conditions
	OTime	1.66822	hr	Oxygen time to run-out
5.27	R		cm	Can radius
1	SArea		cm^2/gU	Specific Surface Area of U particles
	Deriv	.272221		d(Tcenter-Twall)/dTcenter
19	rho		gU/cm^3	Density of uranium
.26	phi			Packing density, U cm^3 / Can cm^3
4559	dHrxn		J/gU	Heat of Reaction
76086	K0		gU/(s*cm^2)	Reaction rate coefficient - Pearce <100%
11490	Te		K	Reaction rate coefficient - Pearce <100%
.3	n			Reaction rate coefficient - Pearce <100%
3.53	P0		kPa	Vapor pressure of water at T0
300	T0		K	Temperature for P0
	P	4.86373	kPa	Vapor Pressure of Water at Tcenter
.004	Kth		W/cm*K	Thermal Conductivity of U particle bed

NCT - 190 °F Wall Temperature

Input	Name	Output	Unit	Comment
	Tcenter	360.969	K	Temperature at the center of the can
360.9	Twall		K	Temp at the can wall
	HRate	8.03E-6	W/gU	Rate of heat production (w/unlimited O2)
	MaxQ	.288991	W	Maximum heat production (from max KgU)
36000	MaxM		gU	Maximum ES-3100 contents
3.01	MaxO		gO	Maximum ES-3100 Oxygen Content
	RRate	6.34E-5	gU/s	Reaction Rate at given Conditions
	ORate	8.52E-6	gO/s	Oxygen Use rate at given conditions
	OTime	98.1015	hr	Oxygen time to run-out
5.27	R		cm	Can radius
1	SArea		cm^2/gU	Specific Surface Area of U particles
	Deriv	.00607		d(Tcenter-Twall)/dTcenter
19	rho		gU/cm^3	Density of uranium
.26	phi			Packing density, U cm^3 / Can cm^3
4559	dHrxn		J/gU	Heat of Reaction
76086	K0		gU/(s*cm^2)	Reaction rate coefficient - Pearce <100%
11490	Te		K	Reaction rate coefficient - Pearce <100%
.3	n			Reaction rate coefficient - Pearce <100%
3.53	P0		kPa	Vapor pressure of water at T0
300	T0		K	Temperature for P0
	P	4.2474	kPa	Vapor Pressure of Water at Tcenter
.004	Kth		W/cm*K	Thermal Conductivity of U particle bed

Attachment 2. Pyrophoric Size Limits on Small Uranium Metal Pieces

Specific Surface Area:	1.0	cm^2/g
Uranium Metal Density:	19.0	g/cm^3
Surface Area Multiplier:	3.0	

The surface area multiplier is the ratio of the actual surface area divided by the simple geometeric surface area.

Spheres - Minimum Safe Diameter

Limiting diameter	0.9474	cm	or	0.3730	in	8.459	grams

Rods - Minimum Safe Diameter

Length	Diameter						
0.9 cm	0.9474	cm	or	0.3730	in	12.688	grams
1.0 cm	0.9231	cm	or	0.3634	in	12.715	grams
1.5 cm	0.8000	cm	or	0.3150	in	14.326	grams
2.0 cm	0.7500	cm	or	0.2953	in	16.788	grams
2.5 cm	0.7229	cm	or	0.2846	in	19.495	grams
Infinite	0.6316	cm	or	0.2487	in		

Cubes - Minimum Safe Side Length

Limiting side length	0.9474	cm	or	0.3730	in	16.155	grams

Square Cross-Section Rods - Minimum Safe Side Length

Length	Side						
0.9 cm	0.9474	cm	or	0.3730	in	16.155	grams
1.0 cm	0.9231	cm	or	0.3634	in	16.189	grams
1.5 cm	0.8000	cm	or	0.3150	in	18.240	grams
2.0 cm	0.7500	cm	or	0.2953	in	21.375	grams
2.5 cm	0.7229	cm	or	0.2846	in	24.822	grams
Infinite	0.6316	cm	or	0.2487	in		

Chips & Shards - Minimum Safe Thickness

Length	Width	Thickness						
1.0 cm	0.5 cm	6.0000	cm	or	2.3622	in	57.000	grams
1.5 cm	0.5 cm	2.0000	cm	or	0.7874	in	28.500	grams
2.0 cm	0.5 cm	1.5000	cm	or	0.5906	in	28.500	grams
2.5 cm	0.5 cm	1.3043	cm	or	0.5135	in	30.978	grams
3.0 cm	0.5 cm	1.2000	cm	or	0.4724	in	34.200	grams
Infinite	0.5 cm	0.8571	cm	or	0.3375	in		
1.0 cm	0.6 cm	2.0000	cm	or	0.7874	in	22.800	grams
1.5 cm	0.6 cm	1.2000	cm	or	0.4724	in	20.520	grams
2.0 cm	0.6 cm	1.0000	cm	or	0.3937	in	22.800	grams
2.5 cm	0.6 cm	0.9091	cm	or	0.3579	in	25.909	grams
3.0 cm	0.6 cm	0.8571	cm	or	0.3375	in	29.314	grams
Infinite	0.6 cm	0.6667	cm	or	0.2625	in		
Infinite	Infinite	0.3158	cm	or	0.1243	in		

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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, tin-plated carbon steel, or nickel alloy, and polyethylene or Teflon FEP bottles. 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. 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) 35.2 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 containers, 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 35.2-kg (77.60-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 (35.2 kg of HEU) is 3.2328×10^{-1} TBq (8.737 Ci) when the maximum activity-to-A_2 value is reached at ~70 years from material fabrication. The corresponding maximum number of A_2s carried is 293.99. 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	35.2 (77.60)

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 1.4.8). 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 1.4.8). 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 1.4.8). 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 1.4.8. The welded angle ring (Find Number 3 on Drawing M2E801580A006, Appendix 1.4.8) 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 1.4.8), respectively. Painting and marking requirements for the drum are shown on Drawing M2E801508A001 (Appendix 1.4.8). 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 1.4.8) 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 1.4.8). 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 1.4.8). 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 1.4.8). 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 1.4.8). 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 1.4.8). The containment vessel sealing lid (Drawing M2E801580A015, Appendix 1.4.8) 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 1.4.8) 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 steel, tin-plated carbon steel, or nickel-alloy, and polyethylene bottles or Teflon FEP bottles. The cans shall have a diameter of ≤12.7 cm (5 in.) and heights of ≤44.5 cm (17.5 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. Multiple short cans may be tack brazed together. The polyethylene bottles have a diameter of ~12.54 cm (4.94 in.) and a height of ~22.1 cm (8.7 in.). A total of three polyethylene bottles may be loaded into the containment vessel. The Teflon FEP bottles have a diameter of ~11.91 cm (4.69 in.) and a height of ~23.88 cm (9.4 in.). A total of three Teflon FEP bottles may be loaded into the containment vessel. Polyethylene bags may be used inside or outside any convenience can or bottle. 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 4.45 cm (1.75 in.) in height and a maximum weight ~0.58 kg (1.27 lb). In order to minimize displacement of convenience containers during transport, stainless-steel scrubbers or polyethylene bags may be added on top of the last can or bottle in the containment vessel. If partial loading configurations are employed and empty cans or bottles are used, these empty cans or bottles 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 71.43(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 1.4.8) 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 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 112.92 kPa (16.378 psi) and 406.27 kPa (58.925 psi) attained during NCT (Sect. 2.6.2) 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 3.2328×10^{-1} TBq (8.737 Ci) at 70 years from initial fabrication; the maximum number of A_2s carried is 293.99 at 70 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.

Table 2.2. Category designations for Type B packages

Contents Form/ Category	Category I	Category II	Category III
Special Form	Greater than 3,000 A_1 or greater than 1.11 PBq (30,000 Ci)	Between 3,000 A_1 and 30 A_1, and not greater than 1.11 PBq (30,000 Ci)	Less than 30 A_1 and less than 1.11 PBq (30,000 Ci)
Normal Form	Greater than 3,000 A_2 or greater than 1.11 PBq (30,000 Ci)	Between 3,000 A_2 and 30 A_2, and not greater than 1.11 PBq (30,000 Ci)	Less than 30 A_2 and less than 1.11 PBq (30,000 Ci)

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact , thermal barrier, and neutron poison surrounding the containment boundary. Because the location of the containment boundary within the packaging is stable, the shielding and subcriticality effectiveness of the package is not reduced. The drum assembly for the ES-3100 consists of an internally flanged Type 304L stainless-steel 30-gallon modified drum with two Type 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter and one filled with noncombustible cast neutron absorber; 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 M2E801580A001, Appendix 1.4.8). The drum assembly is maintained when there are no breaches in the drum surface, the lid remains attached, the relative position of the containment boundary is not altered significantly, and no substantial amount of insulation is exposed following testing stipulated in 10 CFR 71.71 and 73. The drum assembly's design requirements for compliance testing are as follows:

1. The drum lid shall remain attached to the drum under all loading conditions.
2. No opening in the drum shall occur large enough to pass a 10-cm cube [10 CFR 71.43(a)].
3. The outer drum's effective diameter shall exceed requirements to maintain subcriticality and shielding effectiveness.
4. The drum assembly shall provide the structural and thermal protection needed to ensure the containment vessel meets the test leakage criteria for both NCT and HAC of $\leq 1.0 \times 10^{-7}$ ref-cm^3/s.
5. Neutron poison remains in place and retains the amount of water needed to maintain subcriticality.

In accordance with NUREG/CR-3854, Part 4.3, for a Category I shipping package, an acceptable specification for a drum 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 MS27683-7 (MIL-D-6054F) and modified as shown on Drawing M2E801508A004 (Appendix 1.4.8). Material, fabrication, and quality control criteria are generally equivalent to those imposed for a DOT Specification 17C drum. The drum weld seam is pressure tested to 68.95 kPa (10 psi) gauge and a rough handling test in accordance with MIL-D-6054F is conducted. As discussed in Sect. 1.2.1.1, the drum used for the ES-3100 is equivalent to or better than that stipulated by NUREG/CR-3854 for a Category I shipping package. In accordance with DOE, a performance-based package is an approved, quality-controlled, hazardous material container that has been tested or analyzed to demonstrate its ability to maintain confinement and/or containment of its contents under both normal use and credible accident conditions as stipulated in 10 CFR 71. The drum assembly and containment boundary have been maintained for the ES-3100 shipping package as demonstrated by test results documented in the test report (Appendix 2.10.7) and the analytical comparisons discussed in Sects. 2.6 and 2.7.

The codes and standards used for design, analysis, and fabrication of the containment vessel's components are satisfied by complying with the appropriate paragraphs in Sect. III, Div. 1, Subsection NB, and Sect. IX of the *ASME Boiler and Pressure Vessel Code*. Nominal dimensions, not minimum dimensions, were used in the design analysis of the containment vessel components. Though not explicitly expressed, the load combinations and tests stated in Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks* are used in the structural evaluation of the containment vessel for both NCT and HAC as depicted in Table 2.3. Acceptance criteria for the containment vessel stresses are shown in Table 2.4 and locations are depicted in Fig. 2.1.

The design internal pressure of 699.82 kPa (101.5 psi) gauge for the containment boundary was generated based on its stress capability before the *ASME Boiler and Pressure Vessel Code* evaluation shown in Appendix 2.10.1 was started. The containment vessel is tested with an internal pressure of 1034.21 kPa (150 psi) gauge or 1.48 times the design pressure, which exceeds the requirement stipulated in Sect. III, Paragraph NB-6221 (a minimum hydrostatic test pressure of 1.25 times the design pressure) and the regulatory requirement of 10 CFR 71.85(b) (1.5 times the maximum normal operating pressure). As shown in Table 2.6, the containment vessel design stresses are well below the allowable stresses (see Fig. 2.1 for stress locations). Therefore, this ES-3100 containment vessel is capable of shipping at a higher internal pressure. The external pressure requirement from 10 CFR 71.73(c)(6) is 150 kPa (21.7 psi) gauge. These design and operating pressures were used to calculate the stresses (Appendix 2.10.1) in all components of the containment boundary, which are well below the allowable limits at all operating conditions. The maximum normal operating pressure calculated for NCT in accordance with 10 CFR 71.4 and 10 CFR 71.71(c)(1) for the bounding load case is 137.92 kPa (20.004 psia). The maximum internal gauge pressure calculated for NCT is 112.92 kPa (16.378 psi), which is the maximum normal operating pressure minus the reduced external pressure condition of 10 CFR 71.71(c)(3) [137.92 – 25.00 kPa (20.004 – 3.626 psia)] (Sect. 2.6.3). A summary of the package's design, NCT, and HAC pressures and temperatures is presented in Appendices 3.6.4 and 3.6.5. Allowable stress intensity limits and calculated stresses at the design evaluation conditions for the containment vessel are summarized in Tables 2.4 through 2.6. The stresses used in the design of all metal containment vessel components are in the elastic range of the material properties.

For conditions addressed by analysis, the margin of safety is calculated. The margin of safety (M.S.) is defined as:

Margin of Safety = Allowable Stress/ Actual Stress – 1.

In Regulatory Guide 7.11, below Table 1, the following quote is found: "Although NUREG/CR-1815 (Ref. 2) addresses the use of ferritic steels only, it does not preclude the use of austenitic stainless steels. Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle failure." According to Regulatory Guide 7.11, because the containment vessel is manufactured from type 304L stainless steel (which is an austenitic stainless steel), "no tests are needed to demonstrate resistance to brittle failure." Therefore, brittle or fatigue failures are not anticipated under any design, transport, accident, or storage condition (Sects. 2.6 and 2.7). Material specifications for the ES-3100 packaging components are listed in Table 2.7.

Table 2.3. Summary of load combinations for normal and hypothetical accident conditions of transport

Normal or Accident Condition	Applicable initial condition									
	Ambient temperature		Insolation		Decay heat		Internal pressure		Fabrication stresses	SAR reference
	38°C	-29°C	Max	0	Max	0	Max	Min		
NORMAL CONDITIONS (analyze separately)										
Hot environment (38°C ambient temperature)			X		X		X		X	Sect. 2.6.1
Cold environment (−40°C ambient temperature)				X		X		X	X	Sect. 2.6.2
Increased external pressure (20 psia)		X		X		X		X	X	Sect. 2.6.4
Minimum external pressure (3.5 psia)	X		X		X		X		X	Sect. 2.6.3
Vibration and shock:	X		X		X		X		X	Sect. 2.6.5[a]
Normally incident to the mode of transport		X		X		X		X	X	
Free drop:	X		X		X		X		X	Sect. 2.6.7[b]
1.2-m drop		X		X		X		X	X	
Compression test	X		X		X		X		X	Sect. 2.6.9[a]
		X		X		X		X	X	
Penetration test	X		X		X		X		X	Sect. 2.6.10[a]
		X		X		X		X	X	
ACCIDENT CONDITIONS (apply sequentially)										
Free drop: 9-m drop	X		X		X		X		X	Sect. 2.7.1[c]
		X		X		X		X	X	
Crush: 9-m drop	X		X		X		X		X	Sect. 2.7.2[c]
		X		X		X		X	X	
Puncture: 1-m drop onto bar	X		X		X		X		X	Sect. 2.7.3[c]
		X		X		X		X	X	
Thermal: fire accident	X		X		X		X		X	Sect. 2.7.4

[a] This condition was conducted at room temperature with atmospheric pressure inside the containment vessel.

[b] This condition was conducted at ambient temperature at the time of the test except for Test Unit-2. The containment vessel was at atmospheric pressure except for Test Unit-2. Justification for compliance with the environmental requirements of Reg. Guide 7.8 is provided in Sect. 2.6.

[c] This condition was conducted at ambient temperature at the time of the test except for Test Unit-2. The containment vessel was at atmospheric pressure except for Test Unit-2. Justification for compliance with the environmental requirements of Reg. Guide 7.8 is provided in Sect. 2.7.

Table 2.4. Containment vessel allowable stress

Stress Category	Maximum allowable stress	
	Level A (NCT)	Level D (HAC)
Primary membrane stress intensity	S_m	Lesser of 2.4 S_m and 0.7 S_u
Primary membrane + primary bending stress intensity	1.5 S_m	Lesser of 3.6 S_m and S_u
Range of primary + secondary stress intensity	3.0 S_m	Not applicable
Fatigue stress range	S_a @ 10^6 cycles	2 S_a @ 10^6 cycles
Buckling	No buckling	No buckling

Table 2.5. Allowable stress intensity (S_m) for the containment boundary construction materials of construction[a]

Description	Specification	S_m
Pipe body (Method 1)	ASME SA-312 welded or seamless pipe, type TP304L stainless steel	8.825×10^4 kPa (12,800 psi)[b]
Formed body, end cap and flange (Method 2)	ASME SA-182, F304L stainless steel	8.825×10^4 kPa (12,800 psi)[b]
Flange and end cap (Method 1)	ASME SA-182 Forging, F304L stainless steel	8.825×10^4 kPa (12,800 psi)[b]
Containment vessel sealing lid	ASME SA-479, stainless steel 304	8.825×10^4 kPa (12,800 psi)[b]
Containment vessel closure nut	ASME SA-479, UNS-S21800, Nitronic 60 SST	1.524×10^5 kPa (22,100 psi)

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A at 148.89°C (300°F).
[b] Lower of two allowable values was chosen to limit deflection of the flange and lid attachment in accordance with note G7 in Table 2A of Part D.

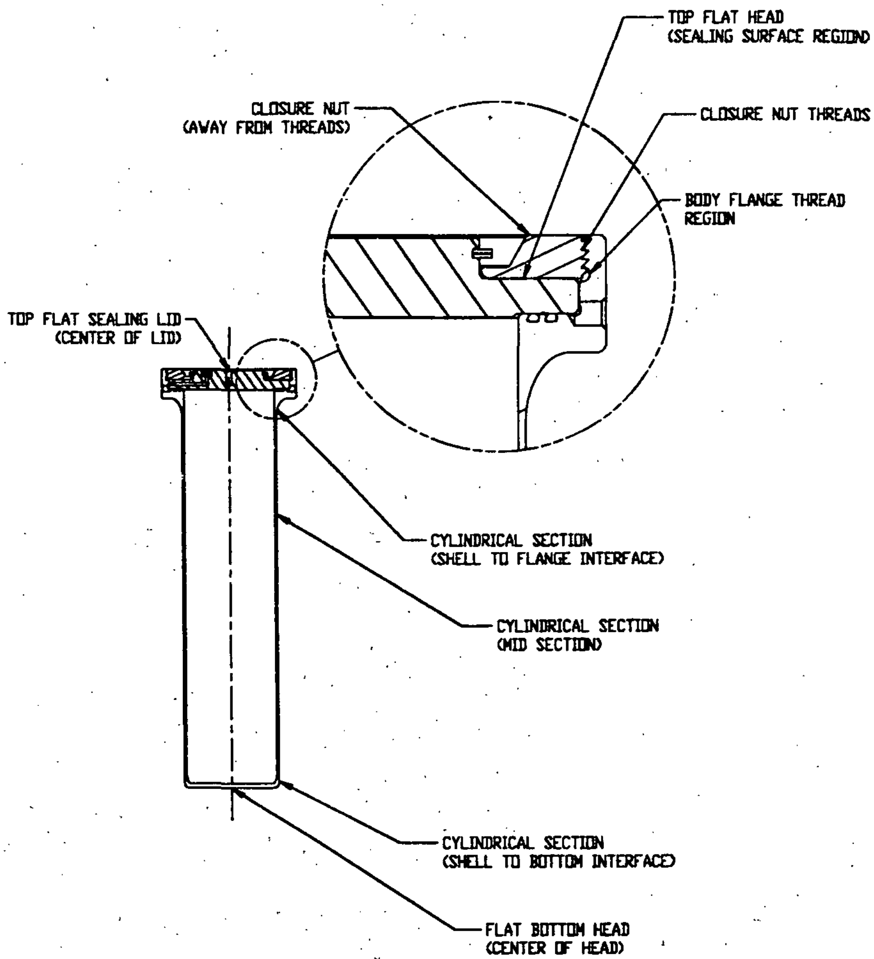


Fig. 2.1. Containment vessel calculated stress locations.

Table 2.6. ES-3100 containment boundary design evaluation allowable stress comparisons [a]

Stress locations shown in Fig. 2.1	Internal pressure design evaluation containment boundary stress @ 699.82 kPa (101.5 psi) gauge		External pressure design evaluation containment boundary stress @ −149.62 kPa (−21.7 psi) gauge		Allowable stress or shear capacity (AS)
	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	6.895×10^3 (1000)	18.20	1.474×10^3 (213.8)	88.8	1.727×10^5 (19,200)[b]
Closure nut ring (Away from threaded portion)	8.621×10^4 (12,504)	4.30	4.246×10^4 [f] (6158)	9.8	4.571×10^5 (66,300)[c]
Top flat head (sealing surface region)	2.717×10^4 (3941)	8.74	1.665×10^4 [f] (2415)	14.9	1.324×10^5 (38,400)[c]
Cylindrical section (middle)	1.999×10^4 (2899)	3.41	4.273×10^3 (619.8)	19.7	8.825×10^4 (12,800)[d]
Cylindrical section (shell to flange interface)	3.016×10^4 (4374)	7.78	1.236×10^4 (1793)	20.4	1.324×10^5 (38,400)[c]
Cylindrical section (shell to bottom interface)	5.127×10^4 (7436)	4.16	1.096×10^4 (1589.8)	23.2	1.324×10^5 (38,400)[c]
Body flange threads load, kg (lb)	2.051×10^3 (4521)	9.01	9.072×10^2 [f] (2000)	21.6	2.053×10^4 (45266)[e]
Body flange thread region (under cut region)	5.926×10^4 (8595)	3.47	2.397×10^4 [f] (3476)	10.0	2.648×10^5 (38,400)[c]
Flat bottom head (center)	4.826×10^4 (7000)	1.74	1.032 × 104 (1496.6)	11.8	1.727×10^5 (19,200)[b]
Closure nut thread load, kg (lb)	2.051×10^3 (4521)	16.29	9.072×10^2 [f] (2000)	38.1	3.545×10^4 (78154)[e]

[a] Stresses are calculated using pressures, gasket and closure nut preload, and nominal dimensions for all containment boundary components in Appendix 2.10.1. Calculated stresses for external pressure were determined by multiplying the stress at the design conditions by a factor equal to the ratio of external pressure to design pressure and adding in contribution from preload. Allowable stress values are taken from Table 2.5.

[b] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.

[c] Stress interpreted as the sum of $P_l + P_b + Q$; allowable stress intensity value is $3.0 \times S_m$.

[d] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.

[e] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area. Thread shear area = 38.026 cm² (5.894 in.²).

[f] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

Table 2.7. ES-3100 packaging material specifications

Component	Specifications
	Drum assembly
Drum washers	1.375 OD × 0.812 ID × 0.25 in. thick, 300 Series stainless steel,
Drum threaded weld studs	5/8-11 × 7/8 Lg, ARC FT, type 304/304L stainless-steel studs
Drum hex nuts	⅝-11 UNC-2B, silicon bronze C65100
Drum lid weldment	Modified 30-gal, 16-gauge (MS27683-61) lid, type 304 or 304L stainless steel; and a 11-gauge thick sheet, type 304 or 304L stainless steel, ASME SA-240
Drum weldment	Modified 30-gal, 16-gauge (MS27683-7), type 304 or 304L stainless steel, ASME SA-240, manufactured per Drawing M2E801580A004 (Appendix 1.4.8)
Drum plugs	Nylon plastic plug, Micro Plastic, Inc.
	Impact limiter, insulation enclosure, neutron absorber, and drum packing material
Insulation and impact limiter (not removable)	Lightweight cast refractory insulation, Kaolite 1600, 358.8 ±48.1 kg/m^3 (22.4 ±3 lb/ft^3) density, cast in stainless-steel shells in the drum and top plug
Neutron absorber	Cat 277-4, 1681.9 +240.3/−80.1 kg/m^3 (105 +15/−5 lb/ft^3) density
Top plug (removable)	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (lifting inserts),
Inner liners	Type 304 or 304L stainless steel, ASME SA-240 (body), ASME SA-479 (modified angle)
Silicone pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Aluminum foil duct tape	McMaster Carr Part # 7616A21, temperature range −40 to 121°C (−40 to 250°F)
	Containment boundary
Containment vessel plug	Part # 04-2126, Modified VCO threaded plug, brass
Containment vessel hoist ring	3052T56, Swivel hoist ring, alloy steel (not used for shipment)
Containment vessel	Method 1: Type TP304L stainless steel ASME SA-312 (welded or seamless pipe body); type F304L, stainless steel, ASME SA-182 (flange, and end cap); type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 SST per ASME SA-479, UNS-S21800 (closure nut)
	Method 2: Type F304L stainless ASME SA-182 (body, flange, and end cap); type 304, stainless steel, ASME SA-479 (sealing lid), Nitronic 60 SST per ASME SA-479, UNS-S21800 (closure nut)
	All components per *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Table 2A
Containment vessel O-rings	Elastomer, ethylene propylene, normal service temperature range of −40 to 150°C, Specification M 3BA712A14B13F17 in ASTM D-2000, per OO-PP-986
Containment vessel lid assembly retaining ring	Part # WSM-400-S02, type 302 stainless steel

Table 2.7. ES-3100 packaging material specifications (cont.)

Component	Specifications
Containment vessel O-ring lubricant	Clear dimethyl siloxane polymer
Containment vessel closure nut lubricant	Krytox #240AC
Containment vessel body dowel pins	0.2501/0.2503 OD × 0.50 long, 18-8 stainless steel
	Containment vessel packing material
Convenience cans	Stainless steel or tinned carbon steel with stainless-steel can handles and nylon-coated stainless-steel wire; nickel-alloy (200 series, passivated) in nylon mesh bag
Convenience Bottles	Polyethylene or Teflon FEP
Silicone rubber pads	Silicone rubber, 22 ±5 Shore A, color black/gray
Can spacers	Stainless-steel can filled with Cat 277-4
Bagging	Polyethylene
Metal scouring scrubbers	Stainless steel, McMaster Carr Part # 7361T13

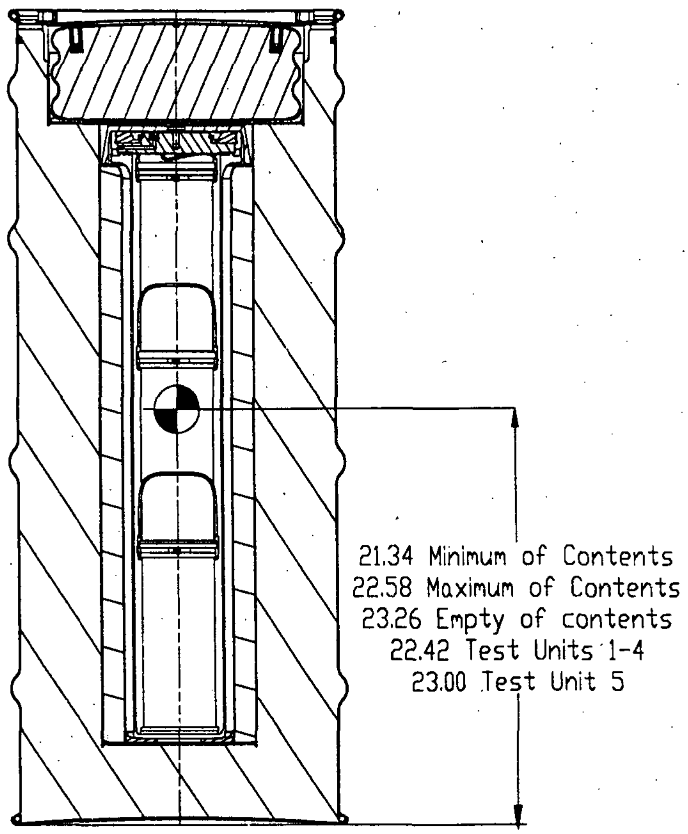
2.1.3 Weights and Centers of Gravity

The weights of the packaging components for the actual proposed contents ready for shipment and the test units are provided in Tables 2.8 and 2.9. The values listed for the test weights are the actual data recorded during compliance testing. The remaining weights listed for the shipping package are calculated weights. Nominal dimensions and densities were used in the calculations. Miscellaneous parts (nuts, and washers) are included.

The range of the centers of gravity for the ES-3100 shipping package with the various HEU arrangements and the test packages is shown in Fig. 2.2. A summary of the calculations are provided in Table 2.10.

2.1.4 Identification of Codes and Standards for Package Design

Based on the discussion in Sect. 2.1.2.2, the shipping package has been designed, analyzed, and will be fabricated, tested and maintained to the requirements of a Category I package. In accordance with the references from NUREG/CR-1815, Table 2.11 describes the appropriate codes and standards that are and will be used to comply with Category I packaging. These requirements have been extracted from NUREG/CR-3854 and NUREG/CR-3019.



Note: Dimensions are in inches.

Fig. 2.2. ES-3100 shipping package center of gravity locations.

Table 2.8. Packaging weights for various ES-3100 shipping package arrangements [a]

Item	ES-3100 Three 10" tall can configuration kg (lb)	ES-3100 Six 4.875" tall can configuration kg (lb)	ES-3100 Five 4.875" tall can configuration kg (lb)	ES-3100 Six 4.75" tall can configuration kg (lb)	ES-3100 Three 8.75" tall can configuration kg (lb)
			Drum assembly		
Drum assembly (drum body, lid, bottom, mid liner, inner liner, cast refractory insulation, cast neutron absorber, nuts, washers, and data plates)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)
Top plug	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)
Silicone support pads	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)
Total drum assembly weight	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**	**131.89 (290.76)**
			Containment Vessel		
Containment vessel (flange, dowel pins, cylindrical body, and end cap)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)
Lid assembly (sealing lid, VCO plug, retaining ring, closure nut and O-rings)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)
Total containment vessel weight	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**
			Contents		
Convenience cans with handles	0.72 (1.59)	1.0 (2.22)	0.84 (1.85)	--	0.67 (1.47)
Silicone vibration pads	0.11 (0.23)	0.18 (0.41)	0.16 (0.353)	--	0.11 (0.23)
Nickel cans	--	--	--	1.84 (4.07)	--
Polyethylene bottles	--	--	--	--	--
Teflon FEP bottles	--	--	--	--	--
Spacers with handles	--	--	1.88 (4.14)	--	1.25 (2.76)
Polyethylene bagging or lifting sling	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)
Metal scouring pads	--	--	--	--	0.14 (0.30)
HEU or HEU/Alloy content	35.2 (77.60)	35.2 (77.60)	35.2 (77.60)	24 (52.91)	35.2 (77.60)
Total proposed content weight	**36.52 (80.52)**	**36.89 (81.33)**	**38.57 (85.04)**	**26.34 (58.08)**	**37.86 (83.46)**
Total shipping package weight	**183.51 (404.57)**	**183.88 (405.38)**	**185.56 (409.09)**	**173.33 (382.13)**	**184.84 (407.51)**

Table 2.8. Packaging weights for various ES-3100 shipping package arrangements [a] (continued)

Item	ES-3100 Three 8.7" tall bottle configuration kg (lb)	ES-3100 Three 9.4" tall bottle configuration kg (lb)	ES-3100 Empty CV configuration kg (lb)	ES-3100 with maximum weight contents kg (lb)
	Drum assembly			
Drum assembly (drum body, lid, bottom, mid liner, inner liner, cast refractory insulation, cast neutron absorber, nuts, washers, and data plates)	121.96 (268.87)	121.84 (268.87)	121.84 (268.61)[b]	121.96 (268.87)
Top plug	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)	8.9 (19.6)
Silicone support pads	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)	1.04 (2.29)
Total drum assembly weight	**131.89 (290.76)**	**131.89 (290.76)**	**131.78 (290.50)**	**131.89 (290.76)**
	Containment Vessel			
Containment vessel (flange, dowel pins, cylindrical body, and end cap)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)	10.18 (22.44)
Lid assembly (sealing lid, VCO plug, retaining ring, closure nut and O-rings)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)	4.92 (10.85)
Total containment vessel weight	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**	**15.10 (33.29)**
	Contents			
Convenience cans with handles	--	--	--	--
Silicone vibration pads	--	--	--	--
Nickel can	--	--	--	--
Polyethylene bottles	0.345 (0.76)	--	--	--
Teflon FEP bottles	--	0.99 (2.18)	--	--
Spacers with handles	--	--	--	--
Polyethylene bagging or lifting sling	0.50 (1.10)	0.50 (1.10)	--	--
Metal scouring pads	--	--	--	--
HEU content	24.0 (52.91)	24.0 (52.91)	--	--
Total proposed content weight	**24.85 (54.77)**	**25.49 (56.19)**	**0**	**40.82 (90)**
Total shipping package weight	**171.84 (378.82)**	**172.47 (380.24)**	**146.88 (323.79)**	**187.81 (414.05)**

[a] Calculated weight using Pro/ENGINEER software with nominal dimensions and densities (Pro/ENGINEER Version 20).
[b] Weight excluding tamper indicating device.

Table 2.9. Compliance test unit weights[a]

Item	Test Unit kg (lb)					
	1	2	3	4	5	6
Drum body assembly[b]	126.6 (279)	127.9 (282)	127.9 (282)	127.9 (282)	128.8 (284)	–
Top plug	9.5 (21)	9.5 (21)	9.53 (21)	8.6 (19)	9.5 (21)	–
Drum silicone support pads	0.9 (2)	0.9 (2)	0.9 (2)	0.5 (1)	0.9 (2)	–
Containment boundary[c]	15.4 (34)	15.0 (33)	15.0 (33)	14.5 (32)	15.0 (33)	15.0 (33)
Mock-up test contents[d]	49.9 (110)	49.9 (110)	50.3 (111)	49.9 (110)	3.6 (8)	
Contents[e]						6.3 (14)
Total test unit weight	202.3 (446)	202.8 (447)	203.7 (449)	201.8 (445)	157.4 (347)	21.3 (47)

[a] Total weight may be different from sum of individual component weights due to scale tolerance of ±0.45 kg (1 lb).
[b] This weight includes the drum, mid liner, inner liner, cast refractory, cast neutron absorber, bottom, lid, washers and nuts.
[c] This weight includes containment vessel cylindrical body, end cap, flanged top, and lid assembly.
[d] This weight includes convenience cans, silicone rubber pads, can handles, spacers (if required), and HEU mockup.
[e] This weight was added to reduce buoyancy of containment vessel during 15-m (50 ft) immersion test.

2.2 MATERIALS

2.2.1 Material Properties and Specifications

The mechanical properties and specifications of the packaging materials are presented in Tables 2.12–2.17. See the drawings in Appendix 1.4.8 for details of all components. Design temperature ranges are listed where they are required to establish the allowable stresses used in the design calculations for the containment boundary (Appendix 2.10.1). Service temperature ranges for the remaining shipping container components were obtained from the references shown in Tables 2.12–2.17.

Appendix 2.10.3 contains the Kaolite 1600 property values presented in Table 2.14, as well as additional Kaolite property and source information. Appendix 2.10.4 contains the Cat 277-4 property and source information. Appendix 2.10.5 contains *Compressive Strength and Coefficient of Thermal Expansion of BoroBond4*. (BoroBond4 was used in the prototype test units, but it is not used in the package to be certified.)

2.2.2 Chemical, Galvanic, or Other Reactions

Requirement. A package must be 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 a possible reaction resulting from inleakage of water, to the maximum credible extent. Account must be taken for the behavior of materials under irradiation.

Table 2.10. Calculated center of gravity for the various ES-3100 shipping arrangements

Content description	**Distance from drum's bottom (in.)**
CYLINDERS, BARS, SLUGS, BROKEN METAL - 35,200 g (77.60 lb) max - no can spacers	
3 full 4.88" cans + 3 empty 4.88" can	21.139
2 full 4.88" cans + 4 empty 4.88" cans	21.405
1 full 4.88" cans + 5 empty 4.88" cans	22.066
3 full 10" cans	22.071
2 full 10" cans + 1 empty 10" can	21.762
1 full 10"can + 2 empty 10" cans	22.075
3 full 8.75" cans	21.875
2 full 8.75" cans + 1 empty 8.75" can	21.662
1 full 8.75"can - 2 empty 8.75" cans	22.060
CYLINDERS, BARS, SLUGS, BROKEN METAL - 35,200 g (77.60 lb) max - with can spacers	
3 full 8.75" cans + 2 spacers	22.245
2 full 8.75" cans + 1 empty 8.75" can + 2 spacers	21.802
1 full 8.75" can + 2 empty 8.75" cans + 2 spacers	22.072
3 full 4.88" cans + 2 empty 4.88" cans + 3 spacers	21.471
2 full 4.88" cans + 3 empty 4.88" cans + 3 spacers	21.500
1 full 4.88" cans + 4 empty 4.88" cans + 3 spacers	22.028
UNX CRYSTALS 24,000 g (52.910 lb) max - with no spacers	
3 full 8.94" high Teflon FEP bottles + bagging	22.674
2 full 8.94" high Teflon FEP bottles + 1 empty 8.94" high Teflon FEP bottle + bagging	22.383
1 full 8.94" high Teflon FEP bottle + 2 empty 8.94" high Teflon FEP bottles + bagging	22.543
OXIDE - 24,000 g (52.910 lb) max - with no spacers	
6 full 4.75" high Nickel cans + bagging	22.631
5 full 4.75" high Nickel cans + 1 empty 4.75" high Nickel can + bagging	22.434
4 full 4.75" high Nickel cans + 2 empty 4.75" high Nickel can + bagging	22.343
3 full 4.75" high Nickel cans + 3 empty 4.75" high Nickel can + bagging	22.366
2 full 4.75" high Nickel cans + 4 empty 4.75" high Nickel can + bagging	22.511
1 full 4.75" high Nickel cans + 5 empty 4.75" high Nickel can + bagging	22.787
OXIDE - 24,000 g (52.910 lb) max - with no spacers	
3 full 8.7" high polyethylene bottles + bagging	22.372
2 full 8.7" high polyethylene bottles + 1 empty 8.7" high polyethylene bottle + bagging	22.210
1 full 8.7" high polyethylene bottle + 2 empty 8.7" high polyethylene bottles + bagging	22.480

Table 2.11. Applicable codes and standards for Category I packaging

	Containment ASME Boiler and Pressure Vessel Code, Sect. III, Subsection NB	Criticality [a]
Materials		Cat 277-4[a]
Base materials	NB-2000 (except NB-2300) and NB-4100	
Welding materials	NB-2400	
Fabrication		
Forming, fitting, aligning, and joint preparation	NB-4200	
Welding	NB-4400	
Qualification of procedures and personnel	NB-4300	
Examination	NB-5000	b
Acceptance testing	NB-6000	c
Quality assurance	Subpart H in Title 10, CFR, Part 71	

[a] NUREG/CR-3854 states "The designer may specify a neutron absorber material by a commercial trade name or as a mixture of elements or common compounds. When appropriate, qualification data should be included to demonstrate that the material functions as specified. When special absorber materials are used to control criticality, an acceptance test should be performed for each container to ensure that the absorber material has been properly installed."

[b] NUREG/CR-3854 states "Packages designed to transport fissile material which contain neutron absorber material should be tested to demonstrate the presence of the neutron absorber material. The test description should include information similar to that requested for gamma shield testing 3.2.1. Fabrication records of the absorber material and its installation and testing should be maintained."

[c] NUREG/CR-3854 states "Gamma scanning or probing may be used to demonstrate the soundness of the neutron absorber. Alternatively, ultrasonic testing may be used. Whatever method is used, the following information should be provided in the test procedure:
(1) Description of the measuring technique including the electronics;
(2) The source type and strength used to measure the neutron absorber effectiveness;
(3) The standards and methods use to calibrate the source, sensors, and other pertinent equipment;
(4) The grid pattern used to check the neutron absorber;
(5) The type of gamma sensor used to measure the neutron absorber effectiveness;
(6) The specific test requirements and measurements;
(7) The acceptance criteria."

Table 2.12. Mechanical properties of the metallic components of the drum assembly[a]

Drum, bottom cover and lid	ASME SA-240 type 304 or 304L, stainless-steel plate	
Inner liners	ASME SA-240 type 304 or 304L, stainless-steel plate	
Top plug weldment	ASME SA-240 type 304 or 304L, stainless-steel plate	
Materials of construction	ASME SA-240 type 304	ASME SA-240 type 304L
Design stress intensity, MPa (ksi) at:		
−40°C (−40°F)	137.9 (20)	115.1 (16.7)
37.78°C (100°F)	137.9 (20)	115.1 (16.7)
93.33°C (200°F)	137.9 (20)	115.1 (16.7)
148.89°C (300°F)	137.9 (20)	115.1 (16.7)
Ultimate strength, MPa (ksi) at:		
−40°C (−40°F)	517.1 (75)	482.6 (70)
37.78°C (100°F)	517.1 (75)	482.6 (70)
93.33°C (200°F)	489.5 (71)	455.7 (66.1)
148.89°C (300°F)	456.4 (66.2)	422.0 (61.2)
Yield strength, MPa (ksi) at:		
−40°C (−40°F)	206.8 (30)	172.4 (25)
37.78°C (100°F)	206.8 (30)	172.4 (25)
93.33°C (200°F)	172.4 (25)	147.5 (21.4)
148.89°C (300°F)	154.4 (22.4)	132.4 (19.2)
Elongation in 5.08 cm (2 in.) (%)	40[b]	40[b]
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at:		
−40°C (−40°F)[c]	0.00001476 (0.0000082)[c]	0.00001476 (0.0000082)[c]
37.78°C (100°F)	0.00001548 (0.0000086)	0.00001548 (0.0000086)
93.33°C (200°F)	0.00001602 (0.0000089)	0.00001602 (0.0000089)
148.89°C (300°F)	0.00001656 (0.0000092)	0.00001656 (0.0000092)
Modulus of elasticity, GPa (Mpsi) at:		
−40°C (−40°F)	197.2 (28.6)	197.2 (28.6)
37.78°C (100°F)	194.0 (28.14)	194.0 (28.14)
93.33°C (200°F)	190.3 (27.6)	190.3 (27.6)
148.89°C (300°F)	186.2 (27.0)	186.2 (27.0)

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Tables 2A, U, and Y-1; and Subpart 2, Tables TE-1, B column, and TM-1.
[b] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part A for ASME SA-240 material.
[c] MIL-HDBK-5H.

Table 2.13. Mechanical properties of the lid fastening components for the drum assembly

Drum weld studs	Specification
Material	ASTM A-493 Type 304/304L stainless steel
Fabrication standard	ASTM F593
Service temperature range, °C (°F)	−40 to 816 (−40 to 1500)[a]
Maximum allowable stress, S, MPa (ksi) at temperatures[a]	
−29°C to 38°C (−20 to 100°F)	129.6 (18.8)
93.3°C (200°F)	115.1 (16.7)
148.9°C (300°F)	103.4 (15.0)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F)[a]	
21.1°C (70°F)	1.53×10^{-5} (8.5×10^{-6})
93.3°C (200°F)	1.60×10^{-5} (8.9×10^{-6})
148.9°C (300°F)	1.66×10^{-5} (9.2×10^{-6})
Drum hex-head nuts	**Specification**
Material	silicon bronze
Fabrication standard	ASTM F-467
UNS designation	C65100[b]
Minimum proof stress, MPa (ksi)	485 (70)[b]
Drum washer	**Specification**
Drum	1.375 OD × 0.812 ID × 0.25 in. thick, Series 300 stainless steel

[a] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 1, Table 3; and Subpart 2, Table TE-1, group 3, B value.
[b] ASTM F-467M.

Table 2.14. Mechanical properties of the cast refractory insulation

Material composition:	Cast Refractory, Kaolite 1600
Flexural tensile strength, kPa (psi) Standard deviation	133 (19.4)[a] 32 (4.7)
Average coefficient of thermal expansion, cm/cm/°C (in./in./°F)	9.07×10^{-6} (5.04×10^{-6})[b]
Average modulus of rupture per ASTM C133-84, kPa (psi)	258.6 (37.5)[c]
Normal operating temperature, °C (°F)	−40 to 871 (−40 to 1600)[c]
Density after curing, kg/m^3 (lb/ft^3)	358.8 (22.4)[c]
Force/deflection curves	Smith, Appendix 2.10.3

[a] *Mechanical Properties of a Low-Density Concrete for the New ES-2 Shipping/Storage Container Insulation, Impact Mitigation Media and Neutron Absorber* (Appendix 2.10.3).
[b] Fax from J. Street, Thermal Ceramics, Inc. (Appendix 2.10.3).
[c] *Product Information, Refractory Castables and Monolithics* (Appendix 2.10.3).

Table 2.15. Mechanical properties of containment vessel O-rings

Material composition:	Ethylene propylene, Specification—M3BA712A14B13F17[a,b]
Normal service temperature range, °C (°F)	−40 to 150 (−40 to 302)[c]
Permissible exposure time at 150°C (302°F), h	1000[c]
Hardness durometer, Shore A	70 ± 5[a]
Minimum elongation, %	100[a]
Fabrication method	Molded[a]

[a] ASTM D-2000.
[b] Per Specification OO-PP-986.
[c] *Parker O-ring Handbook*, Sect. 2.13.2 and Fig. 2-24, p. 2-30.

Table 2.16. Mechanical properties of the metallic components of the containment boundary

Containment vessel: body; flange; and seal lid		Specifications
Material of construction: stainless steel, type 304L		ASME SA-312 (pipe); ASME SA-182 (flange, formed body, or end cap); ASME SA-479 (seal lid)
Design temperature range, °C (°F)		−40 to 176.67 (−40 to 350)
Minimum ultimate strength, MPa (ksi)		482.6 (70)[a]
Yield strength, 0.2% offset, MPa (ksi) at temperatures,	37.8°C (100°F)	172 (25)[a]
	149°C (300°F)	132 (19.2)[b]
	176.67°C (350°F)	126.52 (18.35)[b]
Elongation in 5.08 cm (2 in.), %		57[c]
Modulus of elasticity, GPa (Mpsi) at temperature[b]	−40°C (−40°F)	197.2 (28.60)
	37.78°C (100°F)	194.0 (28.14)
	93.33°C (200°F)	190.3 (27.60)
	121.11°C (250°F)	188.2 (27.30)
	148.89°C (300°F)	186.2 (27.00)
	176.67°C (350°F)	184.4 (26.75)
Allowable stresses (S_m)[d] at 149°C (300°F)		
Welded pipe, MPa (ksi)	149°C (300°F)	115.14 (16.7)
	176.67°C (350°F)	112.03 (16.25)
Forged flanges, lids, end caps, MPa (ksi)	at 149°C (300°F)	115.14 (16.7)
	176.67°C (350°F)	112.03 (16.25)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures[e]	−40°C (−40°F)	0.00001476 (0.00000820)
	37.78°C (100°F)	0.00001548 (0.00000860)
	93.33°C (200°F)	0.00001602 (0.00000890)
	121.11°C (250°F)	0.00001638 (0.00000910)
	148.89°C (300°F)	0.00001656 (0.00000920)
	176.67°C (350°F)	0.00001674 (0.00000930)
Containment vessel closure nut		**Specification**
Material of construction:		Nitronic 60, UNS-S21800
Elongation, %		10–12[f]
Design temperature range, °C (°F)		−40 to 176.67 (−40 to 350)
Ultimate strength, MPa (ksi), room temperature		1655–1813 (240–263)[f]
Yield strength, 0.2% offset, MPa (ksi), room temperature		1344–1496 (195 - 217)[f]
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures[e]	93.33°C (200°F)	0.0000158 (0.0000088)
	204.40°C (400°F)	0.00001660 (0.0000092)

[a] Listed in the appropriate material specification identified under materials of construction.
[b] *ASME Boiler and Pressure Vessel Code,* Sect. II, Part D, Tables Y-1 and TM-1.
[c] Value presented in THERM 1.2, thermal properties database by R. A. Bailey.
[d] *ASME Boiler and Pressure Vessel Code,* Sect. II, Part D, Table 2A.
[e] *ASME Boiler and Pressure Vessel Code*, Sect. II, Part D, Subpart 2, Table TE-1, Column B, except that −40°C is from MIL-HDBK-5H, Table 2.7.1.0.
[f] Value presented in ARMCO NITRONIC 60 Stainless Steel Product Data Bulletin, S-56b.

Table 2.17. Mechanical properties of the cast neutron absorber

Material		Cat 277-4
Service temperature range, °C (°F)		-40 to 150 (-40 to 302)
Modulus of elasticity in tension, GPa (Mpsi) at temperatures [a]		
	-40°C (-40°F)	13.72 (1.991)
	21.11°C (70°F)	4.72 (0.684)
	37.78°C (100°F)	2.78 (0.403)
Coefficient of thermal expansion, cm/cm/°C (in./in./°F) at temperatures [b]		
	-40°C (-40°F)	12.700×10^{-6} (7.056×10^{-6})
	-20°C (-4°F)	13.000×10^{-6} (7.222×10^{-6})
	0°C (32°F)	13.000×10^{-6} (7.222×10^{-6})
	40°C (104°F)	12.600×10^{-6} (7.000×10^{-6})
	60°C (140°F)	11.599×10^{-6} (6.444×10^{-6})
	80°C (176°F)	10.400×10^{-6} (5.778×10^{-6})
	100°C (212°F)	9.700×10^{-6} (5.389×10^{-6})
	120°C (248°F)	9.101×10^{-6} (5.056×10^{-6})
Poisson Ratio		
	-40°C (-40°F)	0.33 [a]
	21.11°C (70°F)	0.28
	37.78°C (100°F)	0.25
Density, g/cm³ (lb/in.³)		1.682 (0.0608)

[a] *Mechanical Properties of 277-4* (Appendix 2.10.4).
[b] *Thermophysical Properties of Heat Resistant Shielding Material* (Appendix 2.10.4).

Analysis. Starting with the outer components, the packaging consists of the drum (austenitic type 304 stainless steel), weld studs (austenitic stainless steel), nuts (silicon bronze), insulation (cast refractory), neutron absorber (Cat 277-4), silicone support pads, containment vessel (austenitic type 304L stainless steel), closure nut (Nitronic 60), silicone support pads, can spacers (stainless steel and Cat 277-4), stainless-steel scrubbers, convenience cans (stainless steel, tin-plated carbon steel, or nickel-alloy [series 200, passivated]), polyethylene or Teflon FEP bottles, polyethylene bags, and the HEU contents.

The cast refractory insulation (Kaolite) is contained between the drum and mid liner and within the top plug assembly's stainless-steel sheet metal. Due to the alkaline nature of this material, greater permanence of the surrounding structure is assured. Also, this material has been used successfully for years as an insulation heat treatment liner adjacent to metal surfaces of furnaces.

The cast neutron absorber (Cat 277-4) is contained between the inner liner and mid liner. During the casting process, the chlorine content is limited to 100 parts per million. The small quantity of chlorine will not affect the stainless-steel liners.

The nuts used to attach the drum to the lid are silicon bronze. All other metal components of the packaging are either stainless steel, Nitronic 60, or tinned steel. All stainless-steel components are passivated per ASTM A380, Paragraph 6.4, and Table A2.1, Part II. Prior to assembly, the packaging will be kept inside a building or transported between buildings in an enclosed truck. The assembled components are protected from the weather and inspected at the time of packaging; therefore, the package will not contain any free water at the time it is loaded for transport. Under NCT, the only moisture present will be the relative humidity or moisture absorbed by the cast refractory or neutron absorber materials. When the package is subjected to a water-spray type environment, some water may leak into the cavity formed by the inner liner and occupied by the containment vessel. To minimize the possibility of any potentially corrosive situation, a visual examination of the interior surface of the inner liner and the exterior surface of the containment vessel shall be conducted prior to packing and following transport of the shipping package (see Sect. 7). Any free water present and any corrosion discovered shall be promptly removed.

During immersion under HAC, water can enter the holes at the top of the drum, be absorbed into the cast refractory material, and fill all void spaces within the drum and inner liner. The insulating value of the insulation material may be decreased, and an overall weight increase would occur. The most important consideration is that the containment boundary remain intact and leaktight. This situation has been evaluated by completely immersing the containment vessel in a tank simulating 0.9-m and 15-m (3- and 50-ft) immersion depths. The containment vessel remained intact and water tight, as demonstrated by the analysis and testing discussed in Sect. 2.7.

All physical contact between the convenience cans and the containment vessel wall, bottom, or top is minimized through the use of the silicone support pads. The polyethylene or Teflon FEP bottles may be in contact with the stainless steel of the containment vessel, but will not react. All cans and bottles will provide the necessary separation of the HEU contents from the containment vessel walls. The passivated Nickel-alloy cans are galvanically similar to the stainless steel of the containment vessel and thus will not react. Additionally, polyethylene bagging may be used around the convenience container (in some cases the HEU is bagged inside the convenience container) as required by packaging personnel. Therefore, galvanic corrosion between the containment vessel wall and convenience containers is highly unlikely. In addition, the environment inside the containment vessel is free of electrolytic solutions, further assuring there will be no galvanic reactions occurring inside the containment vessel.

For pyrophoric considerations, broken metal and alloy pieces shall be of a size that: a) the specific surface area does not exceed 1 cm^2/g, or b) will not pass freely through a mesh size of 3/8 in. (9.53 mm). Incidental small particles which do not pass the size restriction tests, and powders, foils, turnings, and wires may only be shipped if they are in a sealed, inerted container.

The containment boundary remains intact even when the drum and inner liner are filled with water; therefore, the package is acceptable to the maximum credible extent from the standpoint of chemical, galvanic, or other reactions.

2.2.3 Effects of Radiation on Materials

The HEU material is not irradiated. The neutron and photon dose rates (Sect. 5) are well below those required to damage any of the package materials by radiolytic interactions.

2.3 FABRICATION AND EXAMINATION

2.3.1 Fabrication

2.3.1.1 Drum assembly fabrication

The drum assembly is fabricated in accordance with equipment specifications JS-YMN3-801580-A002 (Appendix 1.4.2), JS-YMN3-801580-A003 (Appendix 1.4.4), and JS-YMN3-801580-A005 (Appendix 1.4.5). The later two specifications control the casting of the Kaolite 1600 and Cat 277-4 materials inside the liners, spacer cans and the top plug as appropriate.

The drum assembly and top plug are fabricated according to the design drawings (Appendix 1.4.8), and the portions of the codes, standards, and regulations to the extent described below:

1. *ASME, Boiler and Pressure Vessel Code*, Sect. VIII, Division 1, 2004 edition;

2. *ASME, Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2004 edition;

3. *ASME, Boiler and Pressure Vessel Code*, Sect. IX, 2004 edition;

4. Military Standard, MS27683, *Drum, Metal-Shipping and Storage 16 to 80 Gallons*; and

5. ASTM A 380-99e1, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems*.

Detailed dimensional requirements, and the materials of construction are called out on the drawings in Appendix 1.4.8. Except for the weld studs, documented Certified Material Test Reports (CMTRs) are provided for all materials used in weldments for the fabrication of the drum, including weld filler metal. The CMTRs are traceable to heat numbers and demonstrate compliance with the SA or SFA material specifications called out. For all other materials, documented Certificates of Compliance (CoC) are provided certifying that the materials provided comply with the requirements stated on the drawings and specifications. All welding is done in accordance with welding procedure specifications that are written and performance qualified in accordance with the ASME B&PV Code, Section IX. All welders are performance qualified to weld using these procedures, and their qualifications documented in accordance with the ASME Code, Section IX. The welding fabrication requirements stated in the ASME Code, Section VIII, Division 1, paragraphs UW-26 through UW-48 are met. All butt welds in rolled sheet, pipe and angle joints are full penetration butt welds. With the exception of the seam welds in the drum body, all welds shall be done by the GTAW, GMAW, PAW or a Capacitive Discharge (CD) stud welding process. The weld filler metal used in the fabrication of the drum assembly is procured to comply with the SFA specifications of Section II, Part C of the ASME Code that are stated in the welding procedure specifications. Weld filler metal is procured traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler. The control of weld filler permits a weld examiner to be able to determine the heat number of the weld filler used in any weld on the drum assembly. Weld symbols are provided on the drawings indicating for each weld the type of weld and dimensions of weld. These weld symbols are interpreted in accordance with the American Welding Society, Section A2.4.

2.3.1.2 Containment boundary fabrication

The containment boundary consists of the containment vessel, lid assembly and inner O-ring. The containment vessel is manufactured in accordance with the applicable requirements stated in the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB for Class 1 Components as described on the drawings in Appendix 1.4.8 and equipment specification JS-YMN3-801580-A001 (Appendix 1.4.3). The containment vessel is fabricated according to the design drawings and the following codes, standards, and regulations as described in JS-YMN3-801580-A001.

1. *ASME, Boiler and Pressure Vessel Code*, Sect. III, Division 1 Subsections NB and NCA, Class 1 Components, 2004 edition;

2. *ASME, Boiler and Pressure Vessel Code*, Sect. II, Parts A and C, 2004 edition;

3. *ASME, Boiler and Pressure Vessel Code*, Sect. IX, 2004 edition; and

4. ASTM A 380-99e1, *Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment and Systems.*

Detailed dimensional requirements, and the materials of construction are called out on the drawings in Appendix 1.4.8. CMTRs are provided for the materials used to fabricate these components in accordance with NCA-3860. The suppliers of these materials will meet the requirements of NCA-3800. Such parts are traceable to each containment vessel by means of a serial number. The fabricator maintains control of materials to ensure this traceability. Other metallic materials, and the O-ring seals are supplied with CoCs in accordance with NCA-3862(g) and (h). The weld filler metal used in the fabrication, and repair welding as permitted, of the containment vessels meets the applicable requirements of NB-2400. It is procured to comply with the SFA specifications of Section II, Part C of the ASME B&PV Code that is stated in the fabricator's welding procedure specifications. Weld metal is procured traceable to heat numbers, and CMTRs are furnished for each heat of weld wire filler used. The results of the delta ferrite determination is included in the CMTR for the weld filler metal (see NB-2433). There are two containment vessel assemblies shown on drawing M2E801580A012 (Appendix 1.4.8), part number M2E801580A012-1, and M2E801580A012-4. Part number M2E801580A012-4 is fabricated by welding a forged bottom and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. All welds on the containment vessels are accomplished by either the GTAW or GMAW process, manual or automatic, at the discretion of the fabricator unless specifically called out on the drawings. Backing rings, even if removed after the weld has been made, are not be used. As previously stated, weld symbols are provided on the drawing indicating the type of weld and dimensions of the weld. These weld symbols are interpreted in accordance with the American Welding Society, section A2.4. The forming, fitting and alignment requirements stated in paragraph NB-4200 are met in the fabrication of the containment vessels unless more stringent requirements are called out on the design drawings.

The preferred fabrication method for the containment vessel body (part number M2E801580A012-1), is from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.4.3), and shown on the design drawings. Such processes may include forging, flow forming, or metal spinning. The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA 182 for Grade F304L for a forged component. After final forming, parts are solution annealed and quenched per the requirements of ASME SA 182 for Grade F304L. A certified heat treatment report is provided stating the following information for each furnace charge: the serial numbers of the containment vessel bodies heat treated in the furnace charge, the time and date of the heat treating, the person responsible for the heat treating, the time-temperature profile of the furnace and representative parts of the furnace charge, the quench medium, and all other pertinent details of the heat treating. Such a heat treating report is required for all heat treating, both in process annealing and final heat treatment.

2.3.2 Examination

2.3.2.1 Examination of the drum assembly fabrication

The drum and top plug assemblies are examined and tested according to the design drawings, and the portions of the codes, standards, and regulations to the extent described below:

1. *ASME, Boiler and Pressure Vessel Code*, Sect. VIII, Division 1, 2004 edition;

2. *ASME, Boiler and Pressure Vessel Code*, Sect. V, 2004 edition; and

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

All welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity using a written weld examination procedure. Weld examiners are qualified to perform visual weld inspections in accordance with SNT-TC-1A (2001 Edition), "Personnel Qualification and Certification in Nondestructive Testing;" or ANSI/ASNT CP-189 (2001 Edition), "ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel;" published by the American Society for Nondestructive Testing. ASME Boiler and Pressure Vessel Code, Section IX is to be employed as the applicable requirement. Section VIII of the ASME B&PVC Code is invoked for acceptance criteria for Code specified examinations which are to be performed in accordance with the provisions of ASME B&PVC Section V. Any indication of inclusions, cracks, or porosity in the welds is cause for rejection. The item may be reworked to meet the specifications. The weld examination procedures, the weld examiners qualifications, and the weld examination reports are submitted to BWXT Y-12 for records. The acceptance criteria for joint fit-up and alignment, and for visual examination of welds are given in the ASME B&PV Code, Section VIII, Division 1, paragraphs UW-31 through UW-36. In addition, any visible defects such as lack of fusion, lack of penetration, linear or crack-like defects, and visible porosity, are cause for rejection. Straightening, flattening, and forming by mechanical or thermal means of some features and components after welding may be required to ensure proper assembly. The surfaces of areas of the weldment that have been worked are visually examined to ensure that no cracks are present or that the weldment has not been degraded. Adjacent welds to these areas shall are also visually examined. The acceptance criteria is that no cracks are found. The areas worked and the visual inspections are noted on the dimensional inspection report. The external seam weld of the drum assembly is pressure tested by attaching removable lids on both the top and bottom false wire locations and injecting water and air inside the assembly up to the final pressure of 149.61 kPa (21.7 psia). After all testing, inspection and final machining, the drum assembly and top plug are dimensionally inspected. The dimensions, and features such as flatness, run-out, etc, to be inspected are indicated on the design drawings. A written inspection report is prepared, submitted and maintained for each ES-3100 drum assembly.

The above examination criteria address the stainless-steel components. However, the drum assembly also consists of the Kaolite 1600 material and the Cat 277-4 neutron poison. Acceptance criteria for the installation of the Kaolite 1600 material are addressed by specification JS-YMN3-801580-A003 (Appendix 1.4.4). This specification controls and documents the raw materials used for mixing, casting and vibration methodology, and the baking of the material inside the drum assembly. The final acceptance criterion is achieved by producing a cast Kaolite 1600 material density of 358.8 ± 48 kg/m^3 (22.4 ± 3 lb/ft^3). Acceptance criteria for the installation of Cat 277-4 neutron poison are addressed in specification JS-YMN3-801580-A005 (Appendix 1.4.5). This specification also controls and documents the raw materials used for mixing, casting and vibration methodology, and the final density of the casting [1682 +240/-80 kg/m^3 (105 +15/-5 lb/ft^3)]. Further examination criteria to verify the concentration and homogeneity of the Cat 277-4 in each drum assembly are also provided in specification JS-YMN3-801580-A005. The various parameters specified in NUREG/CR-3854 and in Table 2.11 for a neutron poison are addressed in detail in this specification.

2.3.2.2 Examination of the containment vessel fabrication

The containment vessel is examined and tested according to the design drawings and the following codes, standards, and regulations as described below:

1. *ASME, Boiler and Pressure Vessel Code*, Sect. III, Division 1 Subsections NB and NCA, Class 1 Components, 2004 edition;

2. ANSI N14.5-1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*;*ASME, Boiler and Pressure Vessel Code*, Sect. V, 2001 edition and 2002 and 2003 addenda;

3. ASME, B & PVC, Section V, 2001 edition and 2003 addenda; and,

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

Procured materials are examined in accordance with the applicable paragraphs of NB-2500, and meet the stated acceptance criteria. The results of these examinations are be included with the CMTRs provided to BWXT Y-12. All welded or weld-repair surfaces shall be visually examined by a qualified weld examiner for indications of inclusions, cracks, or porosity. ASME Boiler and Pressure Vessel Code, Section IX is to be employed as the applicable requirements. Section III of the ASME B&PVC Code is invoked for acceptance criteria for Code specified examinations which are to be performed in accordance with the provisions of ASME B&PVC Section V. Prior written approval is obtained for any weld repair on materials, and the weld repair areas are both surface and volumetrically examined. The repair area is noted in a sketch supplied with the CMTR for the material that was weld repaired and the documented results of the weld examination are provided to BWXT Y-12. The markings on the weldment materials are not removed until after all weld examination is complete. The heat numbers of base metals and weld filler are required on all weld examination reports. Control of weld filler by the fabricator permits a weld examiner to be able to determine the heat number of the weld filler used in any weld on the containment vessel.

As previously stated, the containment vessel body may be fabricated by two different methods shown on drawing M2E801580A012 (Appendix 1.4.8). Part number M2E801580A012-4 is fabricated by welding a forged bottom, and forged top flange to a cylindrical shell machined from seamless pipe as shown on the drawing. Prior to welding these components, all weld preparation areas and the surfaces within one inch of the weld are examined visually and with liquid penetrant. The acceptance criteria for these examination are those stated in NB-5130(a) through NB-5130(d). The applicable requirements in paragraphs NB-5110, NB-5120, NB-5210, NB-5220, NB-5260, and NB-5300 apply to the containment vessels. The plug weld shown on Drawing M2E801580A015 (Appendix 1.4.8) shall be examined visually and with penetrant. The applicable requirements in paragraphs NB-5110, and NB-5350 shall apply to the plug weld. Materials used in the penetrant examination of welds and in the final surface examination of finished components (see Section 3.7) shall be specifically recommended by their suppliers for use with austenitic stainless steels, and copies of the certification of contaminant content of materials used (see ASME, Section V, Article 6, T-641) shall be supplied with the examination reports. Repair welding shall meet the applicable requirements of NB-2500. Certified written weld examination reports together with the corresponding material surface examination reports, and weld map shall be submitted as stated in the procurement specification for the containment vessel. Weld examination reports for all weld and surface examination shall include: the containment vessel serial number, a weld map showing the location of the weld and examination area, the welder's name, the examiner's name, the time and date of the weld examination, the examination procedure(s) number used, the WPS number, the heat numbers of the materials joined, the heat number of the weld filler, and examiner's remarks. The examiner's remarks shall include the results of the examination and acceptance, or rejection of the weld based on the stated criteria. One set of radiographs shall be provided with radiographic examination reports. If the weld or surface is rejected, a description of the defect and sketch showing the location shall be provided.

The nonwelded containment vessel body, part number M2E801580A012-1, shall be formed from a single forged billet or bar by any process that meets the requirements stated in JS-YMN3-801580-A001 (Appendix 1.4.3), and shown on the design drawings (Appendix 1.4.8). Such processes may include forging, flow forming, or metal spinning. The formed, heat treated, and finished machined containment vessel body shall meet the applicable requirements of ASME SA 182 for Grade F304L for a forged component. Mechanical properties are verified by testing of coupons. The test coupons are to be machined from the same heats of materials used to form the containment vessel bodies, and shall have the same or greater amount of cold word (plastic strain) as the containment vessels will have as a result of the forming process. The mechanical tensile testing of coupons shall be done in accordance with ASME SA 370. A minimum of six test coupons shall be tested for each final heat treatment furnace charge. The first set of three test coupons, chosen at random, shall be tested without being heat treated. The second set of three or more test coupons shall be heat treated together with the containment vessel bodies, and then tested. The heating rates and maximum temperatures of the test coupons shall be representative of the entire furnace charge. Test coupons are not required to be heat treated with intermediate processing annealing steps, but are required in the final heat treatment furnace charge. The results of all the testing of the sample coupons shall be documented, certified and reported to BWXT Y-12. The mechanical properties test report shall contain the following 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 methods explained in the Sandia National

Laboratory (SNL) Tie-Down Manual [*Tie-down Procedures for Type B Containers Shipped in Safe-Secure Trailer/Safeguards Transporter (SST/SGT)*]. 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. Another method of securing the ES-3100 package is by the use of the Cargo-Restraint Transporter (CRT) or Cargo Pallet Assembly (CPA). In these methods, a frame is positioned around the base and top of either five or six packages. These frames are then chained or locked to the floor as depicted in SNL Tie-Down Manual. Tension is applied to the chains to eliminate any slack. 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 a test plan developed by the National Transportation Research Center (NTRC) at the Oak Ridge National Laboratory (ORNL) (Appendix 2.10.8). Testing of ES-3100 prototype units was performed at the NTRC facility, 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

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
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 specimen testing are documented in Y/DW-1890 (Smith and Byington, Appendix 2.10.3) and Y/DW-1972 (Smith, Appendix 2.10.3). Upon further review of the data, the new test data was somewhat stiffer in the cold/high-density specimens than the data previously used in Y/DW-1972 (Smith, Appendix 2.10.3). Therefore, in order to encompass the extremes of all existing data, an additional drop simulation sequence using the new bounding curves has been conducted on the ES-3100 package as documented in Appendix 2.10.2. In addition to the analytical effort, the ES-3100 Test Unit-2 was pre-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 ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 hours. After this initial period, the control on the environmental chamber was set to −42.8°C (−45° F) for at least 48 hours. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box and transported to the NTRC. High-temperature [up to 38°C (100°F)] behavior was not addressed. However, in light of the fact that the insulation material is typically used as a cast refractory insulation in furnace applications, and that structural tests were performed in the range of 20.8 to 30.6°C (69.4 to 87°F) or just 7.4 to 17.2°C (13 to 30°F) below the high-temperature limit, it is not anticipated that any decline in impact absorption would be detrimental at 38°C (100°F).

2.6 NORMAL CONDITIONS OF TRANSPORT

This section demonstrates compliance with 10 CFR 71.43(f) and with 10 CFR 71.51(a)(1) and (b) following the tests and NCT conditions stipulated in 10 CFR 71.71. It is shown that the package will not experience any loss in shielding effectiveness or spacing and will not release any radioactive content or undergo leakage of water into the containment vessel during exposure to NCT. The four tests (water spray, free drop, compression, and penetration) made on Test Unit-4 were conducted in the 20.8 to 22.4°C (69.4 to 72.4°F) range, with the 1.2-m drop test conducted at 22.4°C (72.4°F). The maximum regulatory reference air leakage rate is $\leq 3.8430 \times 10^{-3}$ ref-cm^3/s. Compliance with this permitted activity release limit is not dependent on filters or mechanical cooling systems. Following NCT compliance testing, the package was subjected to the sequential HAC test battery.

Title 10 CFR 71.71(b) specifies that the tests for NCT be conducted at the most unfavorable ambient temperature within the range of −28.89 to 38°C (−20 to 100°F). The drum is fabricated from type 304 stainless steel, and the containment boundary is fabricated from type 304L stainless steel, which is particularly suitable for low-temperature service. The Izod impact strength for the stainless steel used in the package components remains constant over a large range [specifically, from 21.11 to −195.5°C (70 to −320°F)] (*Stainless Steel Handbook*). Tensile strength increases from a minimum of 4.826×10^5 to 1.696×10^6 kPa (70,000 to 246,000 psi), and the yield strength increases about 10% over the same temperature range. The O-rings in the containment vessel have a normal service temperature range of −40 to 150°C [−40 to 302°F (Table 2.15)]. The normal service temperature range of the drum and containment vessel is −40 to 426.7°C (−40 to 800°F) [ASME, B&PV Code, Sect. II, Part D]. At −28.89°C (−20°F), the impact limiting material has been shown by tests to be stiffer than at 22.4°C (72.4°F). This condition has been evaluated by the compliance testing conducted on Test Unit-2. The reduction in tensile strength of the stainless steel from 22.4 to 38°C (73 to 100°F) is only approximately 2%, and the impact-limiting material test trends show that the impact-limiting material may become slightly softer. However, these slight reductions in tensile strength and absorption characteristics should not affect the results significantly compared to those conducted at 38°C (100°F).

Title 10 CFR 71.71(b) also states that the initial internal pressure within the containment system during NCT drop testing shall be considered as the maximum normal operating pressure. The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.6.4 and discussed in Sects. 2.6.1.1 and 3.4.2. As noted in these sections, the internal pressure is calculated to be 137.92 kPa (20.004 psia). As shown in Appendix 2.10.1, the design absolute pressure of the containment vessel is 801.17 kPa (116.2 psia), and the hydrostatic test pressure stipulated in JS-YMN3-801580-A001 is 1135.57 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 137.92 kPa (20.004 psia) during NCT would have no detrimental effect. Table 2.20 provides a summary of the pressures and temperatures in the various shipping configurations. As discussed in Sect. 2.6.1.4, the containment vessel and the closure nut stresses for this pressure condition are well below the allowable stress values.

Title 10 CFR 71.71(c) specifies that the package service temperature must extend from −40 to 38°C (−40 to 100°F) with solar insolation. As shown in Sect. 3.4.1 and calculated in Appendix 3.6.2, the upper service temperature with solar insolation is calculated to be 87.81°C (190.06°F) for an empty ES-3100 containment vessel. Thermal cycling of the packages over the above temperature range from −40°C (−40°F) is considered an unlikely event, and the change would occur over a long period of time. In any event, the 127.81°C (230.06°F) thermal cycle would not result in brittle fracture or fatigue failure in the packaging. The acceptability of the packaging against brittle fracture is discussed in Sect. 2.6.2. The only concern for fatigue or endurance failure is related to the containment boundary cyclic pressure changes as the temperature varies from low to high. A 25°C (77°F) ambient temperature normally exists for the containment boundary during assembly. The containment boundary is sealed at an absolute pressure of ~101.35 kPa (14.70 psi). The internal absolute pressure at an average gas temperature of 87.81°C (190.06°F) is 137.92 kPa (20.004 psi) for the ES-3100 containment vessel (Table 2.20). The absolute internal pressure at −40°C or −40°F is 76.74 kPa (11.13 psi) for the containment vessel. Therefore, the maximum cyclic pressure differential for the containment vessel from low to high temperatures is (137.92 − 76.74) kPa or 61.18 kPa (8.874 psi). This cyclic pressure is insignificant when considering the integrity of the containment boundary as shown by the stress levels discussed in Sect. 2.6.1.3.

The ES-3100 package has been tested to determine the effectiveness of the package following a sequential NCT 1.2-m (4-ft) drop test and an HAC test battery. Testing conducted on Test Unit-4 showed that there would be no loss or dispersal of radioactive contents and no significant increase in external surface radiation levels if the actual contents had been subjected to these tests, and no substantial reduction in the effectiveness of the packaging to survive the HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Table 2.20. Summary of temperatures and pressures for NCT

Average gas evaluation temperature °C (°F)	Containment vessel absolute internal pressure kPa (psia)
−40 (−40) [a]	76.74 (11.13)
25.0 (77) [b]	101.35 (14.70)
87.81 (190.06) [c]	137.92 (20.004)

[a] Analysis conducted with no decay heat load in accordance with 10 CFR 71.71(c)(2).
[b] Assembly temperature and pressure.
[c] Due to the lack of measurable off-gassing, all ES-3100 containment vessel configurations with solar insolation, and 0.4 W decay heat produce the same internal pressure (Appendix 3.6.4).

2.6.1 Heat

Requirement. Exposure to an ambient temperature of 38°C (100°F) in still air and insolation as stated in 10 CFR 71.71(c)(1).

Analysis. An increase in ambient temperature to 38°C (100°F) with insolation will have no effect on the ability of the containment boundary to provide containment.

The maximum normal operating pressure is defined in 10 CFR 71.4 as the maximum gauge pressure that would develop in the containment system in a period of 1 year under the heat conditions specified in 10 CFR 71.71(c)(1). The internal pressure developed under these conditions in the ES-3100 containment vessel is calculated in Appendix 3.6.4 and discussed in Sects. 2.6.1.1 and 3.4.2. As noted in these sections, the internal pressure varies with temperature. Based on the isotopic determination of the proposed contents, a decay heat of 0.4W was calculated and used for the maximum internal heat load in evaluating the package for NCT (Sect. 3.1.2). The maximum calculated internal absolute pressure in the containment vessel with solar insolation and using the bounding case parameters is 137.92 kPa (20.004 psia). The design absolute pressure of the containment vessel is 801.17 kPa (116.20 psia), and the hydrostatic test pressure is 113.55 kPa (164.7 psia). Thus, increasing the internal pressure of the containment vessel to a maximum of 137.92 kPa (20.004 psia) during NCT would have no detrimental effect. Table 2.20 provides a summary of the pressures and temperatures for the various shipping configurations. As discussed in Sect. 2.6.1.4, the containment vessel and closure nut stresses for these pressure conditions are well below the allowable stress values. If the package is exposed to solar radiation at 38°C (100°F) in still air, the conservatively calculated temperatures at the top of the drum, on the surface of the containment vessel, and on the containment vessel near the O-ring sealing surfaces are 117.72°C (243.89°F), 87.81°C (190.06°F), and 87.72°C (189.9°F), respectively (Sect. 3.4.1). Nevertheless, these temperatures are within the service limits of all packaging components, including the O-rings. The normal service temperature range of the O-rings used in the containment boundary is −40 to 150°C (−40 to 302°F) as shown in Table 2.15.

2.6.1.1 Summary of pressures and temperatures

An ambient temperature of 25°C (77°F) is assumed for the packaging at assembly. Since there are four ventilation holes near the top of the drum, and holes in the liner encapsulating the neutron poison material that are not hermetically sealed, the drum assembly will not become pressurized as the temperature increases. The containment boundary is sealed; thus, the internal pressure will change with temperature. Maximum calculated pressures at various temperatures (Sect. 3.4.1) are listed in Table 2.20.

2.6.1.2 Differential thermal expansion

The drum, inner liners, and containment vessel are all constructed of type 304 or 304L stainless steel. Radial and vertical expansion among these components will not cause any interferences or thermally induced stresses due to design clearances at assembly. Due to similarities of the coefficient of thermal expansion between type 304/304L and the containment vessel closure nut material (ASME SA-479), the compression of the O-rings does not change appreciably during the temperature excursion from 25°C (77°F) to the maximum temperature of 87.81°C (190.06°F).

The Kaolite 1600 insulation and Cat 277-4 material is poured and cast in place during the fabrication of the drum weldment (Drawing M2E801508A002, Appendix 1.4.8). Although some contraction of these material may occur during curing, it is assumed for analysis purpose that a zero gap will exist between the Kaolite and the bounding drum and mid liner and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in coefficients of thermal expansion, some radial and axial interferences are expected due to thermal growth of the inner liners. These radial and axial interferences and induced stresses are calculated in Appendix 3.6.3. A maximum von Mises stress of 6.693×10^4 kPa (9708 psi) was calculated for the inner liners. This stress value is well below the allowable yield strength of 1.324×10^5 kPa (19200 psi) at 148.9°C (300°F). A maximum von Mises stress of 1.379×10^3 kPa (200 psi) and 1.034×10^3 kPa (150 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data and curves presented in Y/DW-1987 (Smith and Byington, Appendix 2.10.4) and the curves presented in Y/DW-1972 (Smith, Appendix 2.10.3) at 38°C (100°F), these compressive stresses are well below the failure limit of ~4.826×10^3 kPa (700 psi) and 5.171×10^3 kPa (750 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

The effects of differences in coefficient of thermal expansion between the HEU contents and their associated convenience cans, polyethylene or Teflon FEP bottles are not addressed. No credit is taken for the ability of the convenience can or bottle to maintain it structural integrity during transport. Section 4 of this document assumes the HEU content is in the form of an aerosol and all is available for release; therefore, no credit for the convenience can or bottle is taken. Based on assembly clearances and the flexibility of the polyethylene or Teflon FEP bottles, no radial or vertical interferences will develop during NCT. Based on assembly clearances and insignificant differences in the coefficient of thermal expansion between the stainless-steel, tin-plated carbon steel, or nickel-alloy convenience cans and the stainless-steel containment vessel, no radial or vertical interferences will develop during NCT testing.

2.6.1.3 Stress calculations

During normal conditions, stresses are only imposed by changes in internal pressure of the containment boundary as the temperature varies slowly over the operating range as shown in Table 2.20. Stress levels imposed on the package during NCT are insignificant, as shown in Tables 2.21, and 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Sect. 2.6.1.4, all stresses in the containment boundary components are well below the *ASME Boiler and Pressure Vessel Code* allowable stress intensity limits.

2.6.1.4 Comparison with allowable stresses

NCT containment vessel stresses are calculated in accordance with the load combinations listed in Table 2.3 and their values are shown in Tables 2.21 and 2.22. The hot environment, cold environment, minimum external pressure, increased external pressure condition, and vibration normally incident to transport are addressed in Sects. 2.6.1, 2.6.2, 2.6.3, 2.6.4, and 2.6.5, respectively. The fatigue or endurance limits for austenitic stainless steel are normally assumed to be about one-half the ultimate tensile strength (*Design Guidelines for Selection of Stainless Steel*, pp. 17–18). For type 304 stainless steel, one-half the ultimate tensile strength is 2.4×10^5 kPa (35,000 psi). Tensile and compressive hoop stresses of the magnitude shown in Tables 2.21 and 2.22 are insignificant compared to the endurance limit of 2.4×10^5 kPa (35,000 psi). As shown in Tables 2.21 and 2.22, the containment vessel stresses during NCT are insignificant. Even at the maximum test temperature and internal pressure (Sect. 3.5.3), the stresses in the containment boundaries were insignificant when compared with the allowable stress intensities shown in Tables 2.4 and 2.5. Corresponding calculated stress regions are shown in Fig. 2.1. Thermal expansion or contraction issues are addressed in Sects. 2.6.1.2 and 2.6.2.

2.6.2 Cold

Requirement. An ambient temperature of −40°C (−40°F) in still air and shade, as required by 10 CFR 71.71(c)(2).

Analysis. The drum is fabricated from type 304 stainless-steel sheet (Table 2.7). As discussed in Sect. 2.6, stainless steel is excellent for low-temperature service, particularly regarding tensile and impact strength. The thermal insulation (Kaolite) is a lightweight noncombustible cast refractory made from portland cement and vermiculite. The only moisture available for freezing at −40°C (−40°F) would be moisture that had not been removed during the curing and cool-down phase of fabrication. Because there will be no free water present for freezing and the insulation is a bonded mass of random fibers and cement, the properties of the insulation will not change appreciably. The matrix may become less flexible when subjected to the cold temperature, but the inner liner will remain in the position in which it was placed at the time of fabrication. The Kaolite 1600 insulation and Cat 277-4 materials are poured and cast in place during the fabrication of the drum weldment (Drawing M2E801508A002, Appendix 1.4.8). Although some contraction of these material may occur during curing, it is assumed for analysis purposes that a zero gap will exist between the Kaolite and the bounding drum and mid liner and a zero gap exists between the Cat 277-4 and the two liners. Due to differences in the coefficient of thermal expansion, some radial and axial interference is expected due to contraction of the outer drum and inner liners. These radial and axial interferences and induced stresses are calculated in Appendix 3.6.3. A maximum von Mises stress of 6.115×10^4 kPa (8869 psi) was calculated for the inner liners. This stress value is well below the allowable yield strength of 1.724×10^5 kPa (25000 psi) at −40°C (−40°F). A maximum von Mises stress of 979 kPa (142 psi) and 510 kPa (74 psi) occurs in the Cat 277-4 and Kaolite 1600 materials, respectively. Based on tabulated data and curves presented in Y/DW-1987 (Smith and Byington, Appendix 2.10.4) and the curves presented Y/DW-1972 (Smith, Appendix 2.10.3) at −40°C (−40°F), these compressive stresses are well below the failure limit of ~ 6.895×10^3 kPa (1000 psi) and 5.308×10^3 kPa (770 psi) for the Cat 277-4 and Kaolite 1600 materials, respectively. Therefore, these thermally induced stresses will not reduce the effectiveness of the drum assembly.

The containment boundary is fabricated from type 304L stainless steel, which is suitable for low-temperature service, particularly regarding impact resistance. This material does not show a transition from ductile to brittle failure at this temperature. The *ASME Boiler and Pressure Vessel Code*, Sect. III, Subsection NB-2311, exempts impact testing of type 304L stainless steels. The Izod impact strength for type 304 stainless steel is 149.14 N·m (110 ft-lb) from 21.11 to −195.5°C (70 to −320°F). The tensile strength increases from ~4.826×10^5 to 1.696×10^6 kPa (70,000 to 246,000 psi) between 21.11 and −195.5°C (70 and −320°F), and the yield strength increases about 10% over the same range. NRC Regulatory Guide 7.6, Part B, states, "these designs were made of austenitic stainless steel which is ductile even at low temperatures. Thus, this guide does not consider brittle fracture." The drum, inner liner, top plug, and containment boundary are made from austenitic stainless steel. Similarly, the containment boundary closure nut material is a galling and wear resistant austenitic stainless steel. Therefore, brittle fracture of these structural materials at −40°C (−40°F) is not possible.

The specified O-rings used in the containment boundary have a continuous service temperature range of −40 to 150°C (−40 to 302°F) as shown in Table 2.15. The low temperature extreme has been verified by compliance testing of Test Unit-2 (Sect. 2.7.1.2). Test Unit-2 was pre-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 ORNL and initially setting the chamber control to −56.7°C (−70°F) for 24 hours. After this initial period, the control on the environmental chamber was set to −42.8°C (−45°F) for at least 48 hours. Prior to the initiation of structural testing of this unit, it was removed from the environmental chamber and placed in an insulated box and transported to NTRC for testing.

As previously noted, the containment vessels will be assembled for shipment in a temperature environment of ~25°C (77°F). If the package should be exposed to −40°C (−40°F) for an extended period, all components will equalize near this low temperature. The absolute internal pressure inside the containment boundary would decrease to a pressure of 76.74 kPa (11.13 psi), assuming no decay heating (Table 2.20). Therefore, the pressure differential across the containment vessel at −40°C (−40°F) is −24.61 kPa (−3.57 psia) [76.739 − 101.35 kPa] (11.13 − 14.7 psia). Due to similarities of the coefficient of thermal expansion between type 304/304L and the containment vessel closure nut material (Nitronic 60, ASME SA-479), the compression of the O-rings does not change appreciably during the temperature excursion from 25°C (77°F) to −40°C (−40°F). The calculated stresses shown in Table 2.21 were determined by multiplying the stress at the design conditions (Appendix 2.10.1 and Table 2.6) by a factor equal to the ratio of operating pressure to design pressure and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Sect. 2.6.1.4, all stresses in the containment boundary components are well below the *ASME Boiler and Pressure Vessel Code* allowable stress intensity limits. As demonstrated by the information presented above, the packaging is acceptable for NCT at −40°C (−40°F).

2.6.3 Reduced External Pressure

Requirement. An absolute external pressure of 25 kPa (3.5 psi) is required by 10 CFR 71.71(c)(3).

Analysis. Reducing the absolute external pressure from ambient pressure to 25 kPa (3.626 psi) will have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. This reduced pressure and a maximum internal pressure produces the maximum pressure differential across the containment boundary of 112.92 kPa (16.378 psi) [137.92 − 25 (20.004 − 3.626)]. The containment boundary is designed and fabricated in accordance with Sects. III and IX of the *ASME Boiler and Pressure Vessel Code* for an internal pressure differential of 699.82 kPa (101.5 psi) as shown in Appendix 2.10.1. A summary of the resulting stress intensities at various locations identified in Fig. 2.1 on the containment vessel in comparison with the ASME code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment boundary components are well below the *ASME Boiler and Pressure Vessel Code* allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an absolute external pressure of 25 kPa (3.626 psi).

2.6.4 Increased External Pressure

Requirement. An absolute external pressure of 140 kPa (20 psi) is required by 10 CFR 71.71(c)(4).

Analysis. Increasing the absolute external pressure from ambient pressure to 140 kPa (20.31 psi) would have no effect on the drum assembly because the plastic plugs and aluminum tape covering the ventilation holes for the Cat 277-4 will allow the internal pressure of the drum assembly to equalize. At this increased external pressure, the maximum pressure differential across the containment boundary would be −63.26 kPa (−9.18 psi) [76.74 − 140 (11.13 − 20.31)], assuming the vessel's absolute pressure and temperature to be 76.74 kPa (11.13 psi) and −40°C (−40°F), respectively. Each containment boundary is designed and fabricated in accordance with Sects. III and IX of the *ASME Boiler and Pressure Vessel Code* for a minimum external pressure of 150 kPa (21.7 psi) gauge. A comparison of the resulting stress intensities at various locations on the containment vessel (Fig. 2.1) with the ASME code allowable limits for this condition is shown in Table 2.22. These tabulated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1 and Table 2.6) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on linear elastic material behavior. As shown in Table 2.22, all stresses in the containment boundary components are well below the *ASME Boiler and Pressure Vessel Code* allowable stress intensity limits. Therefore, the ES-3100 packaging is acceptable for NCT at an external absolute pressure of 140 kPa (20.31 psi).

Table 2.21. ES-3100 containment boundary evaluation for both hot and cold conditions[a]

Stress locations shown in Fig. 2.1	Hot conditions [10 CFR 71.71(c)(1)] containment boundary stress @ 36.57 kPa (5.304 psi) gauge		Cold conditions [10 CFR 71(c)(2)] containment boundary stress @ −24.61 kPa (−3.57 psi) gauge		Allowable stress or shear capacity (AS)
	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	3.603×10^2 (52.3)	366	2.425×10^2 (35.17)	545	1.324×10^5 (19,200)[b]
Closure nut ring (away from threaded portion)	4.636×10^4 (6723)	8.9	4.246×10^4 [f] (6158)	9.8	4.571×10^5 (66,300)[c]
Top flat head (sealing surface region)	1.803×10^4 (2615)	13.7	1.665×10^4 [f] (2415)	14.9	2.648×10^5 (38,400)[c]
Cylindrical section (middle)	1.045×10^3 (152)	83.5	7.030×10^2 (102)	124.5	8.825×10^4 (12,800)[d]
Cylindrical section (shell to flange interface)	8.449×10^3 (1225)	30.3	8.034×10^3 (1165.2)	32.0	2.648×10^5 (38,400)[c]
Cylindrical section (shell to bottom interface)	2.679×10^3 (389)	97.8	1.803×10^3 (261.5)	145.8	2.648×10^5 (38,400)[c]
Body flange threads load, kg (lb)	9.669×10^2 (2132)	20.2	9.072×10^2 [f] (2000)	21.6	2.053×10^4 (45266)[e]
Body flange thread region (under cut region)	2.639×10^4 (3828)	9.0	2.256×10^4 [f] (3272)	10.0	2.648×10^5 (38,400)[c]
Flat bottom head (center)	2.522×10^3 (366)	51.5	1.698×10^3 (246.2)	77	1.324×10^5 (19,200)[b]
Closure nut thread load, kg (lb)	9.669×10^2 (2132)	35.7	9.072×10^2 [f] (2000)	38.1	3.545×10^4 (78154)[e]

[a] Calculated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1) by a factor equal to the ratio of operating pressures to design pressures (independent of pressure direction) plus contribution from preload. Allowable stress values are taken from Table 2.5.
[b] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.
[c] Stress interpreted as the sum of $P_l + P_b + Q$; allowable stress intensity value is $3.0 \times S_m$.
[d] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.
[e] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area. Thread shear area = 38.026 cm² (5.894 in.²).
[f] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

Table 2.22. NCT ES-3100 containment boundary stress compared to the allowable stress at reduced and increased external pressures [a]

Stress locations shown in Fig. 2.1	Reduced external pressure [10 CFR 71.71(c)(3)] containment boundary stress @ 112.92 kPa (16.378 psi) gauge kPa (psi)		Increased external pressure [10 CFR 71.71(c)(4)] containment boundary stress @ −63.26 kPa (−9.18 psi) gauge kPa (psi)		Allowable stress or shear capacity (AS)
	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)	M.S.	kPa (psi) or kg (lb)
Top flat portion of sealing lid (center of lid)	1.113×10^3 (161.4)	118	6.236×10^2 (90.4)	211.3	1.324×10^5 (19,200)[b]
Closure nut ring (away from threaded region)	5.130×10^4 (7440.8)	7.9	4.246×10^4 [f] (6158)	9.8	4.571×10^5 (66,300)[c]
Top flat head (sealing surface region)	1.923×10^4 (2789.4)	12.8	1.665×10^4 [f] (2415)	14.9	2.648×10^5 (38,400)[c]
Cylindrical section (middle)	3.225×10^3 (467.8)	26.4	1.808×10^3 (262.2)	47.8	8.825×10^4 (12,800)[d]
Cylindrical section (shell-to-flange interface)	1.109×10^4 (1609)	22.9	9.374×10^3 (1359.6)	27.2	2.648×10^5 (38,400)[c]
Cylindrical section (shell-to-bottom interface)	8.273×10^3 (1200)	31	4.637×10^3 (672.5)	56.1	2.648×10^5 (38,400)[c]
Body flange threads load, kg (lb)	1.092×10^3 (2407)	17.8	9.072×10^2 [f] (2000)	21.6	2.053×10^4 (45266)
Body flange thread region (under cut region)	3.033×10^4 (4399)	7.7	2.397×10^4 [f] (3476)	10.0	2.648×10^5 (38,400)[c]
Flat bottom head (center)	7.788×10^3 (1130)	16.0	4.365×10^3 (633)	29.3	1.324×10^5 (19,200)[b]
Closure nut thread load, kg (lb)	1.092×10^3 (2407)	31.5	9.072×10^2 [f] (2000)	38.1	3.545×10^4 [e] (78154)

[a] Calculated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1) by a factor equal to the ratio of operating pressures to design pressures (independent of pressure direction) plus contribution from preload. Allowable stress values are taken from Table 2.5.
[b] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.
[c] Stress interpreted as the sum of $P_l + P_b + Q$; allowable stress intensity value is $3.0 \times S_m$.
[d] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.
[e] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area. Thread shear area = 38.026 cm² (5.894 in.²).
[f] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

2.6.5 Vibration

Requirement. Vibration normally incident to transportation is required by 10 CFR 71.71(c)(5).

Analysis. Vibration testing on a prototypical ES-3100 package (Test Unit-4) was conducted in accordance with the ES-3100 test plan (Appendix 2.10.8) and documented in the test report (Appendix 2.10.7). Testing was conducted with the package restrained as shown in Fig. 2.3. The containment vessel was assembled with the mock-up content weighing 49.90 kg (110 lb). The total weight of the test unit was 201.8 kg (445 lb). The unit was subjected to an endurance test with random vibrations modeled after the power spectral density plot for the Safe-Secure Trailer/Safeguards Transporter (SST/SGT) vibration envelope in the vertical axis (Cap, Appendix 2.10.6). At this level of vibration intensity, the test unit compares with MIL-STD-810F. MIL-STD-810F is a standard random vibration test for basic transportation vibrations generated by a large truck or tractor-trailer combination. MIL-STD-810F defines 60 min of testing as equal to 1609 km (1000 miles) of common carrier transportation. Assuming that the two random vibration tests are similar in intensity, Test Unit-4 had about 6436 km (4000 miles) of simulated random vibration testing. Based on a nominal shipping distance of 3218 km (2000 miles), Test Unit-4 was subjected to a test that was approximately two times more severe than that required by 10 CFR 71.71(c)(5). As shown by the following paragraphs, containment, shielding effectiveness, and subcriticality were maintained even when the package was subjected to such an arduous environment.

The test was run at ~22.8°C (73°F) rather than at the high or low temperatures specified for NCT. This was reasonable because the thermal coefficients of expansion of the flange and closure nut materials are very close. Therefore, the temperature extremes would not have a significant effect on the closure tightness.

Summarizing 10 CFR 71.43(f), the tests and conditions of NCT shall not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M (Byington 1997) and ES-3100 test packages. Due to the similarities in design, fabrication, and construction materials of the ES-2M and the ES-3100 packages, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M Test Unit-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, Test Unit-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, Test Unit-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Additionally, Test Unit-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of both the NCT and HAC tests, the containment vessel was removed, and a full-body helium leak test was conducted to the leaktight criterion ($\leq 2 \times 10^{-7}$ cm^3/s) in accordance with ANSI N14.5-1997.

Following compliance testing of the ES-3100 shipping package, minor changes were incorporated into the proposed design as described in Sect. 2.5.1. During the vibration test, the shipping package is restrained from movement in the vertical direction with a tie-down arrangement similar to that used on a

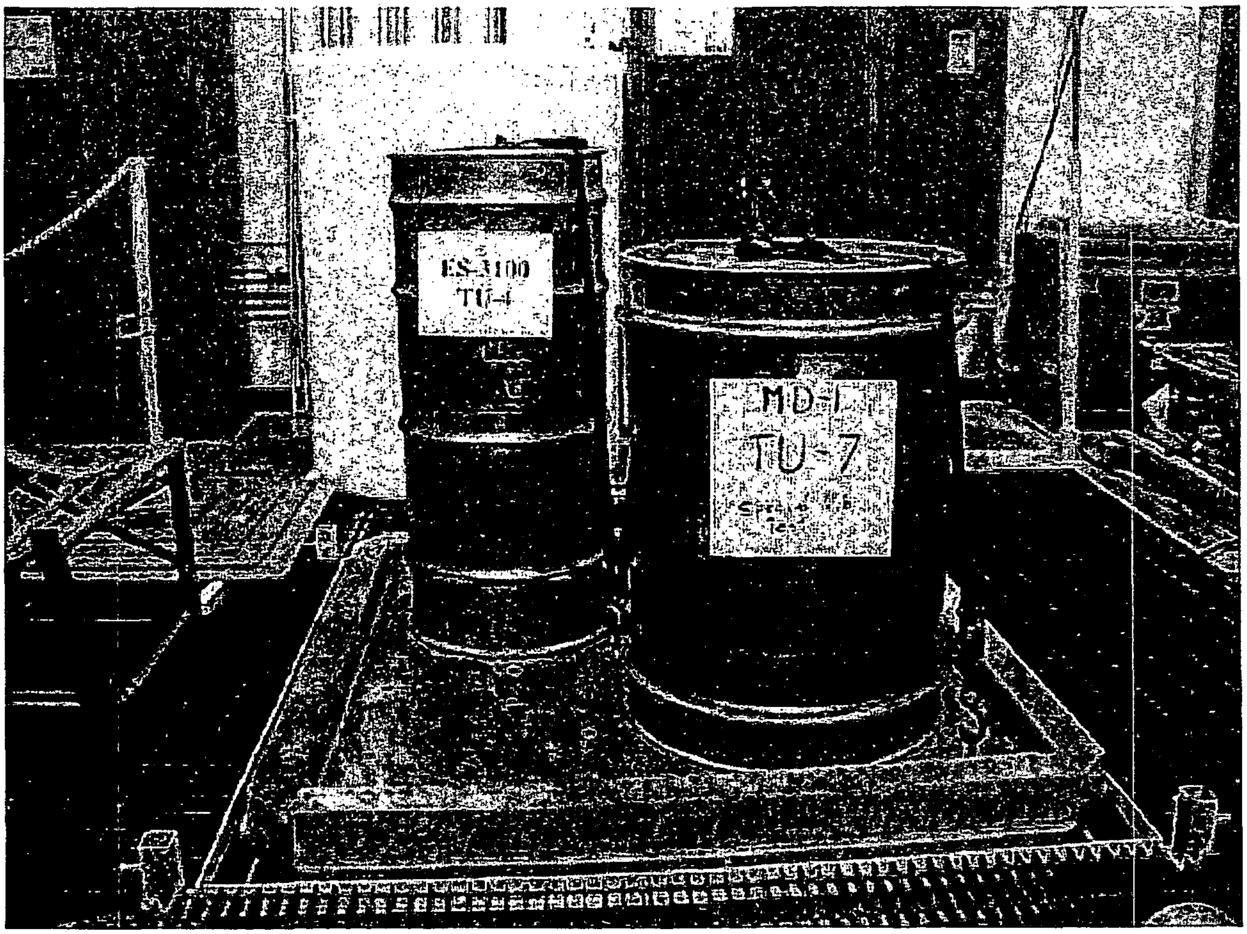


Fig. 2.3. ES-3100 vibration testing arrangement.
(MD-1 test unit removed during actual testing.)

SST/SGT for a single package. Based on the acceleration spectral density presented in Appendix 2.10.6, the largest contributor to shipping package motion is in the vertical direction. Since the containment vessel and contents are not restrained within the inner liner cavity, the containment vessel is free to bounce up and down. In the vertical direction, the top plug and the bottom of the inner liner restrict the movement of this vessel. Since the inner liner contour has not changed with respect to the containment vessel, and the fact that there are clearances between the containment vessel flange and the inner liner in the vertical direction, the cast neutron poison and inner liner are not directly impacted by the movement of the containment vessel. Therefore, changes in the neutron poison and minor radial dimension changes in the mid liner will not affect the outcome from vibration testing. Based on the success of the previously tested units and the fact that these proposed changes will have little or no effect on testing, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) are satisfied.

Procedures will be followed to ensure that the packaging is assembled as specified (Sect. 7). The drum, lid, and fasteners are refurbished as required before each use. The ⅝-in.–diam flange nuts on the drum are torqued to 40.67 N·m (30 ft-lb) nominal. The closure nut on the containment boundary is torqued to 162.7 N·m (120 ft-lb) nominal. The package is acceptable for vibration normally incident to transport in an SST/SGT.

2.6.6 Water Spray

Requirement. A water spray that simulates exposure to rainfall of ~5.08 cm (2 in.) per hour for at least 1 h is required by 10 CFR 71.71(c)(6).

Analysis. A water spray of 5.08 cm (2 in.) per hour was directed from above and around the periphery of the ES-3100 Test Unit-4 for a minimum of 1 h as shown in Fig. 2.4. The drum had four plastic plug-sealed ventilation holes near the top which prevents water from entering the insulation cavity. Aluminum duct tape, covering the installation holes in the mid liner, prevents water from entering the neutron poison cavity. There was evidence of water leakage into the volume between the containment boundary and the inner liner at the conclusion of the test. Water entered this cavity through the holes provided in the lid for the TID lugs, but none penetrated the containment boundary. The criticality analysis shown in Sect. 6 was conducted with moderation by water to the most reactive credible extent and close full reflection of the containment system by water on all sides. Because the package remained subcritical under these conditions, the ES-3100 package is acceptable for use under the water spray conditions of NCT.

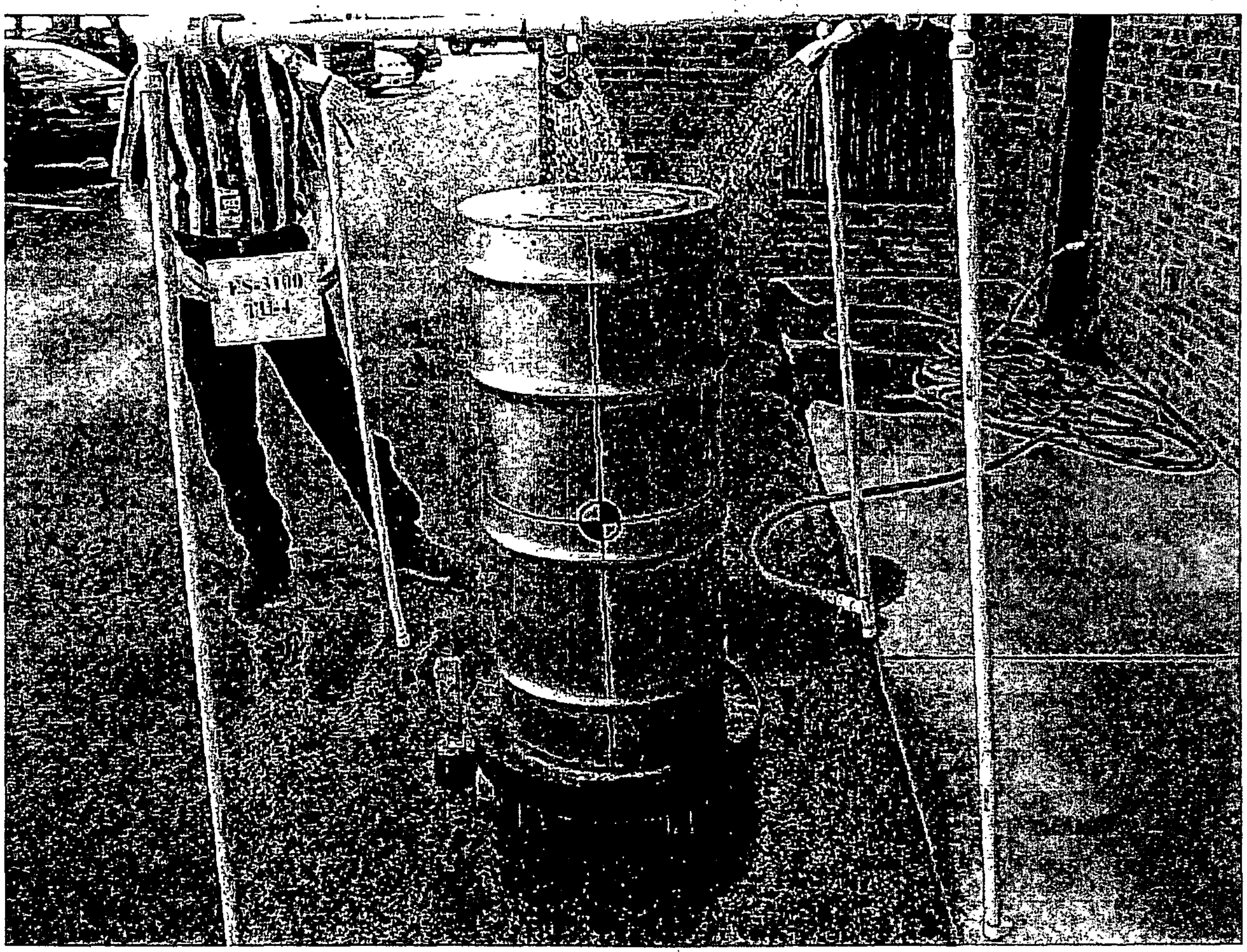


Fig. 2.4. Water spray test arrangement for Test Unit -4.

2.6.7 Free Drop

Requirement. A free drop of 1 m (4 ft) onto a flat, essentially unyielding, horizontal surface in a position for which maximum damage is expected is required by 10 CFR 71.71(c)(10). This test shall be made between 1½ and 2½ h after the conclusion of the water spray test (Sect. 2.6.6).

Analysis. The ES-3100 test package, Test Unit-4, previously sprayed with water (Sect. 2.6.6) with a measured gross weight of 201.85 kg (445 lb) and containing a content weight of 49.90 kg (110 lb) was tested in accordance with 10 CFR 71.71(c)(7). The temperature and pressure at the time of the drop test was 22.8°C (73°F) and ~101.35 kPa (14.70 psi), respectively. As discussed in Sect. 2.6, the response of the test package would not have been significantly different if it had been tested at the extremes of the temperature range dictated by 10 CFR 71.71(b) with the containment vessel at the maximum normal operating pressure.

The essentially unyielding surface used for this 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).

Test Unit-4 was dropped from 1.2 m (4 ft) in a vertical position, with the drum's top initially striking the unyielding surface (Fig. 2.5). This attitude was assumed to be the most vulnerable orientation for producing damage to the sealing surfaces of the containment vessel and for introducing buckling into the cylindrical portion of the containment vessel body. The long axis of the drum was 0° from vertical. The test package made a free fall, with initial contact on the drum's lid. Damage consisted of shortening the drum height from 110.81 cm (43⅝ in.) to 110.49 cm (43½ in.) There were no breaks in the drum assembly. Additional details and sketches can be obtained from the test report (Appendix 2.10.7). Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the drop test damage would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(7).

In addition to the tests conducted on Test Unit-4, all test units (except Test Unit-6) were initially subjected to a free drop of 1.2-m (4 ft) onto a flat, essentially unyielding horizontal surface. As shown in Table 2.18, the orientations for these drops were two drops bottom to lid slapdown with the long axis of the drum ~ 12° from parallel to the drop pad; one drop with the long axis of the test unit parallel to the drop pad; one drop with the center of gravity drop over the drum/lid interface with the long axis of the drop rotated ~24.6° from perpendicular to the drop pad; and one with the long axis of the drum perpendicular to the drop pad. Package description, damage from testing, and drop orientation concerns are discussed in Sect. 2.7.1 for each test unit. Following the 1.2-m (4-ft) drop, each of these test units was subjected to the full HAC sequential test battery. The robustness of the ES-3100 containment vessel was demonstrated through whole boundary helium leak testing to $\leq 2.0 \times 10^{-7}$ cm^3/s (leaktight). This helium leak test eclipses the required criteria for both NCT and HAC based on the bounding case contents. Visual inspection of the containment boundaries showed no distortion or deformation from testing. Therefore, based on the various drop orientations, the severity of the HAC test sequence, and the testing conducted on Test Unit-4, the ES-3100 shipping package has been shown to meet the requirements of 10 CFR 71.43, 71.51(a)(1), and 71.71(c)(7).

2.6.8 Corner Drop

Requirement. 10 CFR 71.71(c)(8) requires a free drop onto each corner of the package in succession, or in the case of a cylindrical package, onto each quarter of each rim, from a height of 0.3 m (1 ft) onto a flat, essentially unyielding, horizontal surface. This test applies only to fiberboard, wood, or fissile

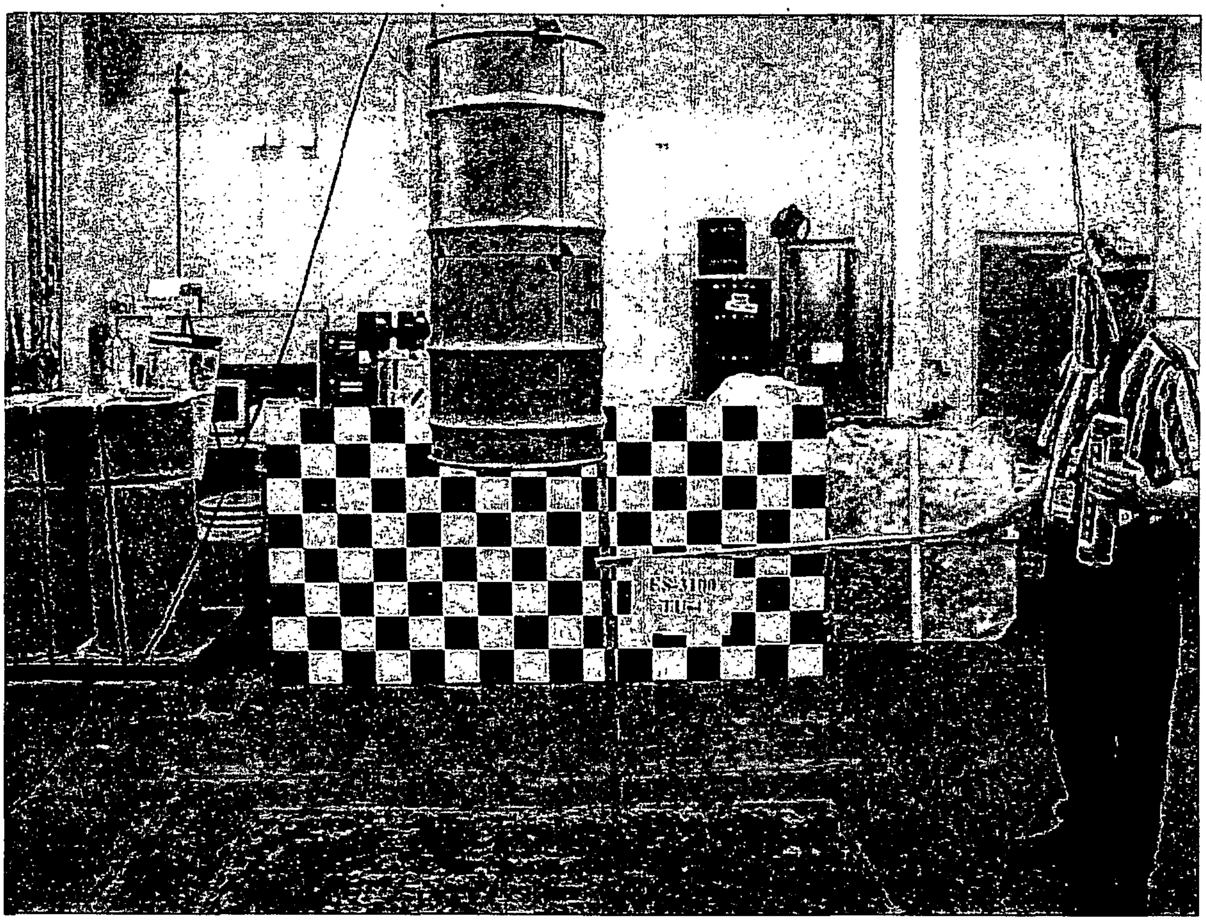


Fig. 2.5. NCT free drop test on Test Unit-4.

material rectangular packages not exceeding 50 kg (110 lb) and fiberboard, wood, or fissile material cylindrical packages not exceeding 100 kg (220 lb).

Analysis. This test is not applicable because the range of package weights for the ES-3100 [146.88 kg (323.79 lb) to 187.81 kg (414.05 lb)] exceed the above-weight restrictions for fissile material cylindrical packages.

2.6.9 Compression

Requirement. Title 10 CFR 71.71(c)(9) requires that packages weighing up to 5000 kg (11,000 lb) must be subjected for a period of 24 h to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported. The compressive load must be the greater of the following:

1. the equivalent of five times the weight of the package; or,
2. the equivalent of 13 kPa (2.0 psi) multiplied by the vertically projected area of the package.

Analysis. The proposed maximum weight of the ES-3100 shipping package is calculated to be 187.81 kg (414.05 lb) [Table 2.8]. As shown on Drawing M2E801580A010 (Appendix 1.4.8), the data plate states that the maximum gross weight of the ES-3100 shipping package is 190.51 kg (420 lb). In accordance with Item 1 above, the minimum compressive load would be 5 × 190.51 kg or 952.55 kg (2100 lb). The vertically projected area of the package is 1891 cm^2 (293.16 $in.^2$) or the area of the lid weldment. Based on Item 2 above, the minimum compressive load would be 13 kPa × 1891 cm^2 or 250.72 kg (552.75 lb). Therefore, the approach stipulated in Item 1 above represents the greatest compressive load for this configuration. A conservative 1043 kg (2300 lb) compressive load was uniformly applied to the top and bottom of Test Unit-4 for at least 24 h (Fig. 2.6). The test package had been sprayed with water as noted in Sect. 2.6.6. No change in height or diameter of the test unit resulted from the test.

Fig. 2.6. Compression test on Test Unit-4.

Due to the design of the ES-3100 drum lid, the applied compressive load was distributed equally around the lid and supported primarily through the outer drum contour and Kaolite 1600 substrate. Little or no load is transferred to the neutron poison (BoroBond4 in the test units) and internal liners. Therefore, the changes in the design of the liners and neutron poison proposed for this shipping packages should not impact the outcome resulting from compression testing. Based on the results of compliance testing of Test Unit-4 and the insignificant changes in the design, the ES-3100 package meets the requirements of 10 CFR 71.71(c)(9)

2.6.10 Penetration

Requirement. Impact of the hemispherical end of a vertical steel cylinder of 3.2 cm (1.25 in.) diameter and 6 kg (13 lb) mass dropped from a height of 1 m (40 in.) onto the exposed package surface that is expected to be most vulnerable to puncture is required by 10 CFR 71.71(c)(10). The long axis of the cylinder must be perpendicular to the package surface.

Analysis. A 6-kg (13-lb) steel cylinder was dropped from 1 m (40 in.) onto the surface of Test Unit-4, which was previously subjected to water spray, free drop, vibration and compression tests. The penetration bar impacted the side of the drum at the welded seam near the package's center of gravity. The bar did not penetrate the drum, but an indentation 0.64-cm (0.25-in.) deep was recorded at the drum seam weld as shown in Fig. 2.7. The magnitude of this indentation is insignificant. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, the magnitude of indentation would be nearly identical had this test been conducted on the proposed configuration using the Cat 277-4 neutron absorber. On this basis, the ES-3100 package meets the requirements of 10 CFR 71(c)(10).

Fig. 2.7. Penetration test damage on Test Unit-4.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

This section demonstrates compliance with 10 CFR 71.73, "Hypothetical Accident Conditions." It shows that the package will experience no loss in shielding effectiveness or spacing and no release of radioactive content or leakage of water into the containment boundary during HAC. A summary of the tests and analyses conducted on the ES-3100 configuration is shown in Table 2.23.

Title 10 CFR 71.51 requires that the ES-3100 package satisfy the standards under HAC specified in 10 CFR 71.73. For the tests specified in 10 CFR 71.73, five test packages were subjected to the five sequential tests: free drop, crush, puncture, thermal, and immersion. The configuration for Test Units-1 through -4 used full-scale shipping packages with steel mock-ups similar to the maximum contents to be shipped in the ES-3100 configuration. Test Unit-5, also a full-scale shipping package, was dropped with a mock-up of the lightest component proposed for shipping. All test units were first subjected to the NCT free drop from 1.2 m (4 ft). In addition to the 1.2-m (4-ft) drop, Test Unit-4 was also subjected to the full battery of tests in accordance with applicable paragraphs of 10 CFR 71.71(c)(5) through (c)(10) except (c)(8). These preliminary tests were conducted to provide evidence that the ES-3100's ability to withstand HAC testing was not degraded through NCT testing. Demonstration of the ES-3100 package's ability to satisfy the requirements of HAC is provided in the following sections. A summary of the test results is provided in each area of Sect. 2.7; details are documented in the test report (Appendix 2.10.7).

Extensive computer impact simulation and analysis was conducted using LS-Dyna software. (LS-Dyna 2002) The results are documented in Appendix 2.10.2. Early in the design phase, the simulation was used to determine areas of large structural deformation and stress concentrations. Prior to the compliance testing in accordance with 10 CFR 71.71, the simulation was used to determine the drop orientation that would cause the most structural damage to the drum assembly and thereby propose a worst-case scenario for potential breeching of the containment boundary. Prior drop test programs have shown the slapdown orientation to cause the most structural degradation of a drum-style container. Computer software LS-DYNA-3D was used to simulate a 9-m (30-ft) drop orientation at a slapdown angle of 12° with a friction factor of $\mu = 0.0$ as calculated using the computer code Slapdown, Version 05.20.93. Slapdown calculated that no matter what friction factor was assumed, the tail-end velocity peaked at approximately 14° (Handy 1997, Appendix 6.10). The maximum tail-end velocity versus slapdown angle is presented in Fig. 6.10.4 in Handy 1997, and the logic for the development of this figure is explained in Appendix 6.10 in Handy 1997. Due to the mitigating effects of the length to diameter ratios and the relative closeness of the 12° increase in velocity to the maximums (shown in Fig. 6.10.4 in Handy 1997), the 12°slapdown is considered to be representative of the worst-case slapdown. Based on the correlation of data obtained from preliminary drop tests of the similar ES-2M configuration and computer-simulated drops, several orientations were eliminated from the drop test matrix (Table 2.23). Several other impact simulations have been conducted using a wide range of material properties for the impact limiter material (Kaolite 1600) to determine the variance in structural deformation. Results of these simulations are documented in Sect. 5.6 in Handy (1997). Although the analysis shows some variance, the magnitude of difference was not large enough to degrade the performance of the drum assembly and containment boundary. Due to the similarities in design, fabrication, and material used in construction of the shipping packages, these same results would hold true for the ES-3100 package.

Title 10 CFR 71.73(b) requires that the HAC tests, except for the water immersion tests, be conducted at the most unfavorable ambient temperature within the range of −29 to 38°C (−20 to 100°F). This requirement was previously discussed in Sect. 2.6 for NCT, in which it was concluded that the tests performed at 70 to 90°F ambient temperatures should provide essentially the same results, except for thermal, as those made at any ambient temperature between −29 to 38°C (−20 to 100°F). Buckling failures are not anticipated for this package design. This assumption is based on the fact that no evidence of buckling

Table 2.23. Test and analysis summary for the ES-3100 package [a]

Container	NCT water spray, compression, penetration, vibration	1.2-m (4 ft) drop	9-m (30 ft) drop and crush test				1.2-m (4-ft) puncture drop	Preheat over 38°C (100°F)	HAC thermal burn test	O-ring cavity leak check (operational)	Full-body helium leak test [b]	0.9-m (3-ft) immer. test	15-m (50-ft) immer. test
			Top drop	CG over lid corner	Bottom to lid slapdown	Side drop							
TU-1		1—YES			12° 2—YES		3—YES[c]	4—YES	5—YES	6-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 1.6×10^{-7} cm^3/s	8—YES	
TU-2		1—YES				2—YES	3—YES	4—YES	5—YES	6-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES Pulsing between 1.0×10^{-9} to 1.4×10^{-6} cm^3/s	8—YES	
TU-3		1—YES		24.6° 2—YES			3—YES	4—YES	5—YES	6-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 1.0×10^{-7} cm^3/s	8—YES	
TU-4	Yes	1—YES	2—YES				3—YES	4—YES	5—YES	6-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES $2. \times 10^{-7}$ cm^3/s	8—YES	
TU-5		1—YES			12° 2—YES		3—YES	4—YES	5—YES	6-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s	7—YES 3.1×10^{-8} cm^3/s	8—YES	
TU-6										1-YES $\leq 1.0 \times 10^{-4}$ ref. cm^3/s			2—YES
Impact Analysis		YES	YES	YES	YES	YES							
Thermal Analysis	YES[d]							YES	YES[d]				

[a] Numbering refers to sequence of activities.
[b] Full-body helium leak test conducted following HAC testing. Leakage value recorded after 20 minutes of the test period.
[c] Test Unit-1 was puncture tested in four different orientations.
[d] Thermal analysis was conducted to determine time for cooling to -40°C and to evaluate the application of decay heating and insolation during the cool-down phase.

occurred when the package was subjected to the compression test in accordance with 10 CFR 71.71(c)(9); the water immersion tests in accordance with 10 CFR 71.73(c)(5) and 71.73(c)(6); and the 1.2-m and 9-m drop test conducted on Test Unit-4. Code calculations further substantiate that buckling failures of the containment vessel are not anticipated for this package design (Appendix 2.10.1).

Title 10 CFR 71.73(b) states that the HAC initial pressure within the containment boundary vessel during testing shall be considered as the maximum internal normal operating pressure. The internal pressures in the ES-3100 containment vessel at various temperatures for NCT are discussed in Sects. 3.4.1 and 3.4.2 and tabulated in Table 2.20. The maximum normal absolute operating pressure due to insolation and the bounding case parameters is 137.92 kPa (20.004 psia) for the containment vessel. This pressure is well below the design internal gauge pressure of 699.82 kPa (101.5 psi). Increasing the internal pressure in the containment boundary to the value noted above before a free drop (Sect. 2.7.1), crush (Sect. 2.7.2), puncture (Sect. 2.7.3), or water immersion (Sect. 2.7.5) testing would have no detrimental effect on the containment boundary's structural integrity due to the low stresses shown in Table 2.21. Temperature and pressure increases in the containment boundary due to the compliance thermal tests are discussed and evaluated in Sects. 2.7.4 and 3.5.3. A summary of these pressures is presented in Appendix 3.6.5.

Summarizing 10 CFR 71.43(f) and 71.55(d)(4), the tests and conditions of NCT will not substantially reduce the effectiveness of the packaging to withstand HAC sequential testing. The effectiveness of the ES-3100 to withstand HAC sequential testing is not diminished through application of the tests and conditions stipulated in 10 CFR 71.71. The justification for this statement is provided by physical testing of both the ES-2M and ES-3100 test packages, and the analytical structural deformation predicted in Appendix 2.10.2 (summarized in Sect. 2.7.8). Due to the similarities in design, fabrication, and material used in construction of both the ES-2M and the ES-3100 package, the physical characteristics of the Kaolite 1600 will hold true for both designs. The integrity of the Kaolite 1600 is not significantly affected by the NCT vibration and 1.2-m (4-ft) drop tests. Prior to testing the ES-2M design, each test unit was radiographed to determine the integrity of the Kaolite 1600 impact and insulation material. Following casting of the material inside the drum, some three-dimensional curving cracks were seen in some packages near the thinner top sections from the bottom of the liner to the bottom drum edge. After vibration testing, radiography of the ES-2M Test Unit-4 showed that the lower half of the impact limiter was broken into small pieces. In order to evaluate these findings, Test Unit-4 was reassembled and subjected to HAC sequential testing. After vibration and impact testing, many three-dimensional curving cracks were seen around the impact areas, and the inner liner was visibly deformed. Nevertheless, the ES-2M Test Unit-4 maintained the adequate spacing required for shielding effectiveness and subcriticality. Temperatures at the containment boundary were also similar to other packages not subjected to vibration testing prior to HAC testing. No inleakage of water was recorded following immersion. Additionally, Test Unit-4 of the ES-3100 test series was subjected to tests and conditions stipulated in 10 CFR 71.71(c)(5) through (c)(10), excluding (c)(8). Following completion of these NCT tests, the test unit was subjected to the full HAC test battery. Following these tests, the containment vessel was removed and subjected to a full-body helium leak test. Criteria for a leaktight condition was achieved. Based on the success of these units, vibration normally incident to transport does not reduce the effectiveness of the packaging during HAC testing. Thus, the requirements of 10 CFR 71.43(f) and 71.55(d)(4) are satisfied.

2.7.1 Free Drop

Requirement. A free drop of 9 m (30 ft) onto a flat, unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected is required by 10 CFR 71.73(c)(1).

Analysis. Five test packages were drop tested from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(1) with the set up as shown in Fig. 2.8. A description of the drop pad is presented in Sect. 2.6.7. Four different drop positions were used in the testing based on the analytical results from LS-Dyna drop

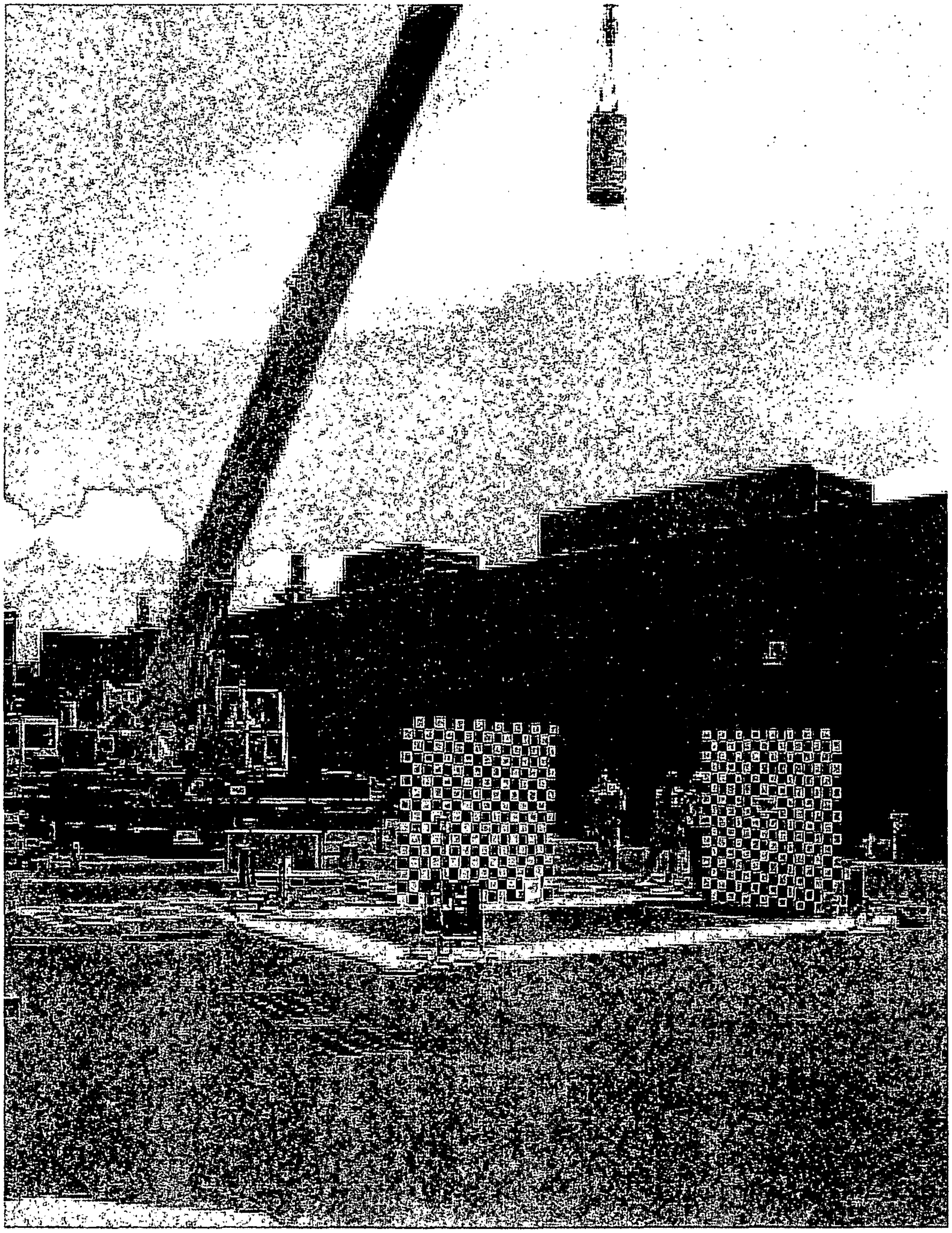


Fig. 2.8. 9-m drop test arrangement for all test units.

simulations. The ES-3100 test units were designated as Test Units-1, through -5. Test Unit-4 was subjected to the full NCT testing (water spray, 1.2-m (4-ft) drop, compression, penetration, and vibration) prior to HAC testing. The gross weight of the ES-3100 test units varied between 157.4 kg (347 lb) and 203.7 kg (449 lb). Mock-up components weighing between 3.6 kg (8 lb) [Test Unit-5] to 50.3 kg (111 lb) [Test Unit-3] were used during testing. Discussion of the damage to each test package resulting from the 9-m (30 ft) drop is given in subsequent paragraphs. Rationale for the four drop positions is included in the discussion for each test unit. Minor changes to the mid liner and the substitution of the neutron poison from BoroBond4 to Cat 277-4 are further evaluated in Sect. 2.7.8.

2.7.1.1 End Drop

Test Unit-4, weighing 201.8 kg (445 lb), was dropped from 9-m (30 ft) with the long axis of the drum perpendicular to the impact surface within 0.2°. The mock-up components are shown on Drawing M2E801580A027. The concern for this drop orientation was that the containment boundary assembly would crush, buckle or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Following initial impact, the package bounced very little before landing on its side. The damage to the drum consisted of reducing the overall height from 43.5 in. [following the 1.2 m (4 ft) drop] to a minimum 42.63 in. The diameter of the drum was measured at six locations along the long axis of the package and at two radial locations. The measurements and pictorials of the damage are recorded on Test Form 1 of procedure TTG-PRF-08 shown in the test report data sheets (Appendix 2.10.7) and are summarized in Tables 2.24 and 2.25 and Fig. 2.9.

Table 2.24. Recorded height damage to Test Unit-4 from 1.2-m and 9-m drop testing

	0°	90°	180°	270°
Pre-drop height (in.)	43.50	43.50	43.63	43.63
Post 1.2-m drop height (in.)	43.50	43.50	43.50	43.50
Post 9-m drop height (in.)	43.00	43.13	42.88	42.63

Table 2.25. Recorded diametrical damage to Test Unit-4 from 1.2-m and 9-m drop tests [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	19.38	19.38	19.38
Top rolling hoop	19.25	19.25	19.13	19.25	19.25	19.88
CG & top rolling hoop	19.25	19.25	19.81	19.25	19.25	19.38
CG rolling hoop	19.13	19.13	19.13	19.25	19.25	19.25
Bottom rolling hoop	19.13	19.13	19.25	19.25	19.25	19.25
Bottom false wire	19.38	19.38	19.25	19.25	19.25	19.25

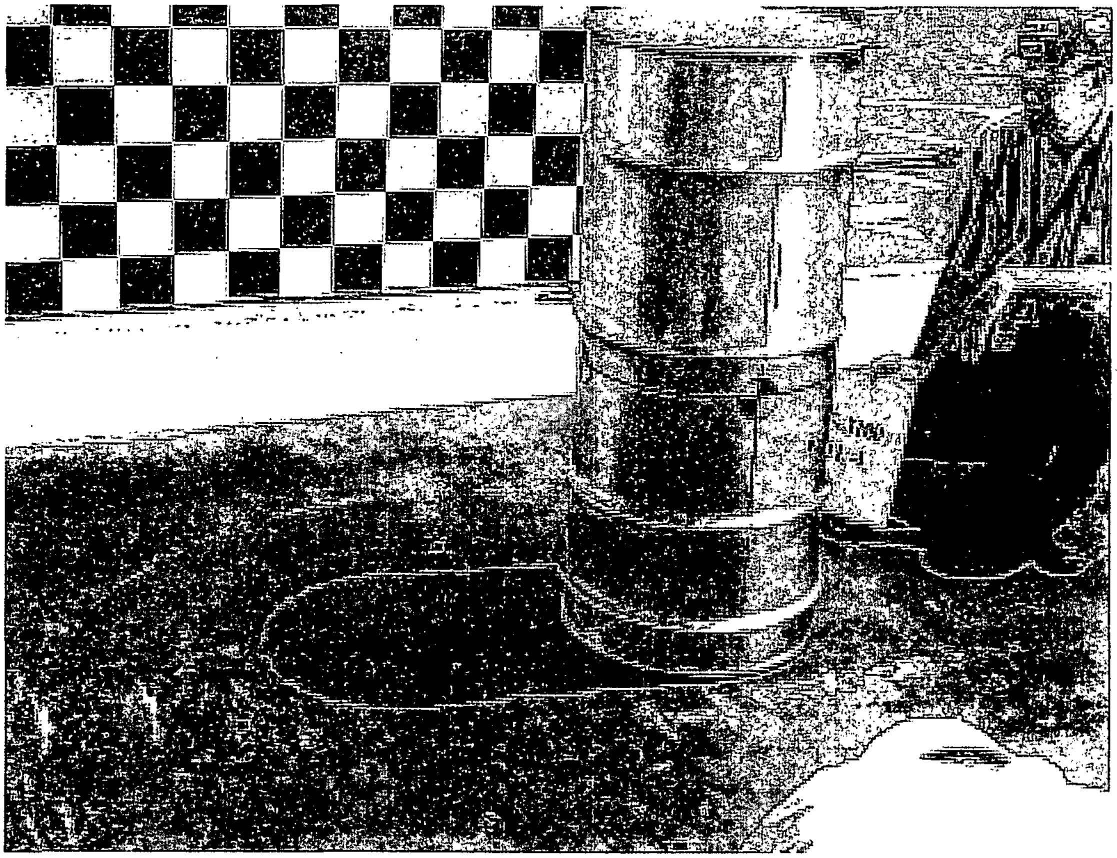


Fig. 2.9. 9-m drop test damage on Test Unit-4.

2.7.1.2 Side Drop

Test Unit-2, weighing 202.8 kg (447 lb) was chilled to −40°C (−40°F) prior to conducting the drop tests. This unit was sequentially dropped from 1.2 m (4 ft), 9 m (30 ft), crushed from 9 m (30 ft), and puncture tested with the long axis of the drum parallel to the impact surface. The mock-up component used in Test Unit-2 is shown on Drawing M2E801580A027 and weighed 49.9 kg (110 lb). There were two concerns for this drop orientation. The primary concern was that the containment boundary assembly would crush or compress the insulation to a thickness that would result in excessive O-ring temperatures during the thermal testing cycle. Another concern was that the cold temperatures might cause excessive loads and deformation in the containment vessel body during impact. This, in turn, might cause leaking above the regulatory limit to occur. 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 24.2°C (75°F). Since it was important to evaluate the package at the regulatory minimum temperature, individual results of each test were not recorded. Time required to measure the package between drops would have allowed the package to further increase in temperature. Cumulative results of damage to Test Unit-2 from drop testing is shown in Tables 2.26, 2.27, and 2.28 and Fig. 2.10.

Table 2.26. Recorded diametrical damage to Test Unit-2 from NCT and HAC drop testing [Diameter (in.)]

Axial measurement location	0 to 180°		90 to 270°	
	Pre drop test	Post drop test[a]	Pre drop test	Post drop test[a]
Top false wire	19.25	17.63	19.25	19.81
Top rolling hoop	19.25	17.38	19.25	19.75
CG & top rolling hoop	19.25	17.00	19.25	20.00
CG rolling hoop	19.25	16.00	19.25	20.25
Bottom rolling hoop	19.25	15.50	19.25	20.13
Bottom false wire	19.25	18.00	19.25	19.38

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.

Table 2.27. Recorded flat contour damage to Test Unit-2 from NCT and HAC drop testing

Axial measurement location	Flat width @ 0° (in.)	Flat width @ 180° (in.)
Top false wire	8	6.25
Top rolling hoop	9	8.88
CG & top rolling hoop	10.13	9.63
CG rolling hoop	9.88	12.00
Bottom rolling hoop	9.88	14.88
Bottom false wire	9.38	0
Crease (see Fig. 2.10 for location)		15.25

Table 2.28. Recorded height damage to Test Unit-2 from NCT and HAC drop testing

	0°	90°	180°	270°
Pre-drop height (in.)	43.50	43.50	43.50	43.50
Post-drop height (in.)[a]	44.75	43.75	42.75	43.63

[a] Includes cumulative damage from 1.2-m drop, 9-m drop, and crush test.

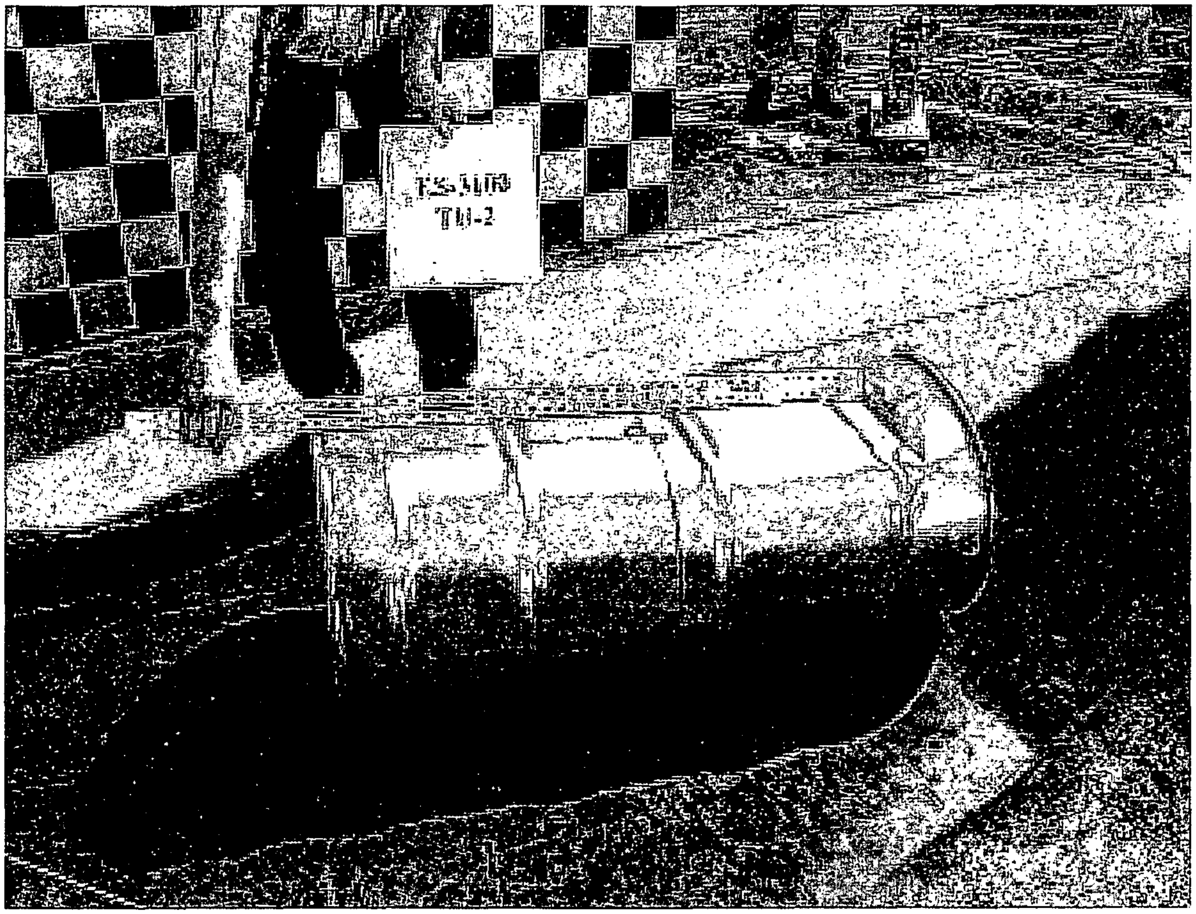


Fig. 2.10. Cumulative damage from 9-m drop and crush testing on Test Unit-2.

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 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

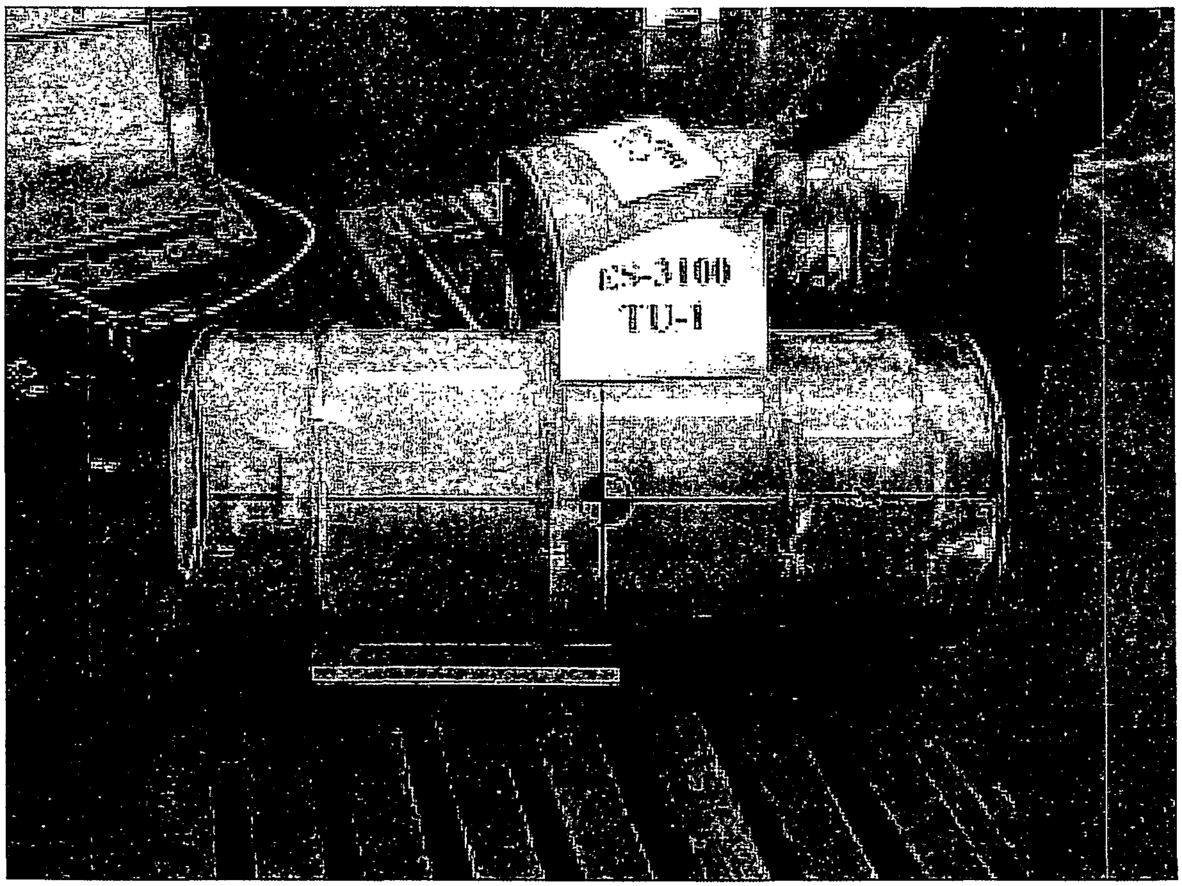


Fig. 2.12. 1.2 and 9-m drop test damage on Test Unit-1.

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

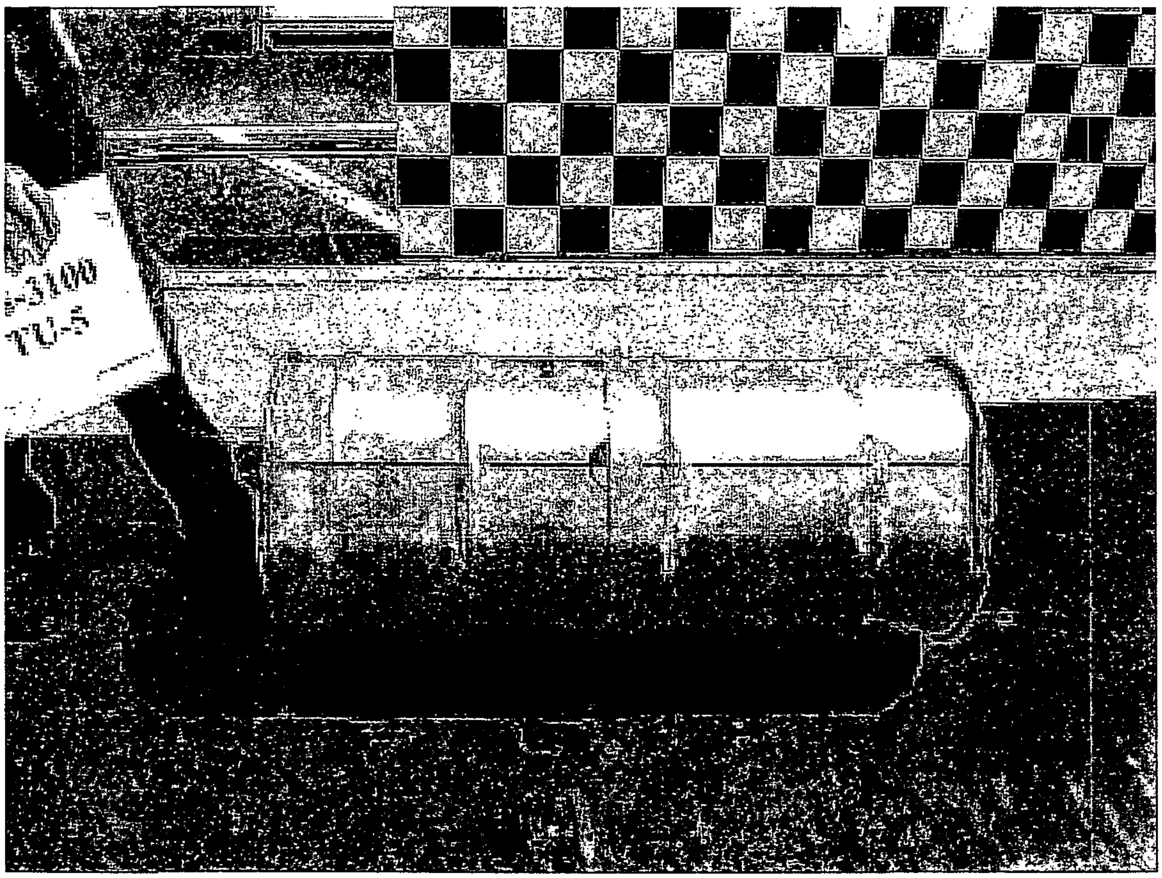


Fig. 2.13. 1.2 and 9-m drop test damage to Test Unit-5.

2.7.2 Crush

Requirement. Title 10 CFR 71.73(c)(2) requires that the specimen be subjected to a dynamic crush test in which the specimen is placed on a flat, essentially unyielding, horizontal surface so as to suffer maximum damage by the drop of a 500-kg (1100-lb) mass from 9 m (30 ft) onto the specimen. The mass must consist of a solid mild steel plate 1 m (40 in.) by 1 m (40 in.) and must fall in a horizontal attitude. The crush test is required only when the specimen has a mass ≤500 kg (1100 lb), an overall density ≤1000 kg/m^3 (62.4 lb/ft^3) based on external dimensions, and radioactive contents >1000 A_2 not as special form radioactive material. For packages containing fissile material, the radioactive contents greater than 1000 A_2 criterion does not apply.

Analysis. Five test packages were subjected to the dynamic crush test from 9 m (30 ft) in accordance with 10 CFR 71.73(c)(2). The previously drop-tested packages (described in Sect. 2.7.1) were restrained in the orientation used for drop testing. Discussion of the damage to each test package that resulted from the crush test is given in subsequent paragraphs, with details given in the test report. (Appendix 2.10.7) Rationale for the three drop positions is included in Sect. 2.7.1 for each test unit. The impact of the steel plate only increased the overall concern for each orientation.

Test Unit-1, weighing 202.3 kg (446 lb), was positioned in a horizontal attitude with the damaged portion of the test unit, resulting from prior drop tests, placed on the drop pad (0° mark facing down on test pad). The 500-kg (1100-lb) crush plate was centered over the sealing lid location on the containment vessel and dropped from 9 m (30 ft) and squarely contacted the top false wire of the drum at an ambient temperature of 29°C (84.2°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.37, 2.38, and 2.39. Since the length of the crush plate did not encompass the entire length of the test package, a crush edge indentation is recorded in Table 2.39. Additional pictorials of damage are shown on Fig. 2.14.

Table 2.37. Recorded height damage to Test Unit-1 from the 9-m crush test

	0°	90°	180°	270°
Pre-crush height (in.)	44.50	43.38	43.25	43.38
Post 9-m crust test height (in.)	44.88	43.38	44.00	43.63

Table 2.38. Recorded diametrical damage to Test Unit-1 from the 9-m crush test [Diameter (in.)]

Axial measurement location	0 to 180°		90 to 270°	
	Pre crush test	Post 9-m crush test	Pre crush test	Post 9-m crush test
Top false wire	18.50	15.63	19.38	20.63
Top rolling hoop	18.50	16.00	19.38	20.43
CG & top rolling hoop	18.50	16.25	19.38	20.25
CG rolling hoop	18.63	16.50	19.38	19.88
Bottom rolling hoop	18.63	18.25	19.25	19.50
Bottom false wire	17.81	17.81	19.38	19.25

Table 2.39. Recorded flat contour damage to Test Unit-1 from the 9-m crush test

Axial measurement location	Flats width maximum @ 0° (in.)	Flats width maximum@ 180° (in.)
Top false wire	9.00	8.50
Top rolling hoop	10.00	10.00
CG & top rolling hoop	10.00	10.13
CG rolling hoop	9.00	10.63
Bottom rolling hoop	8.25	--
Bottom false wire	9.75	--
Dent where edge of plate struck test unit	--	9.13

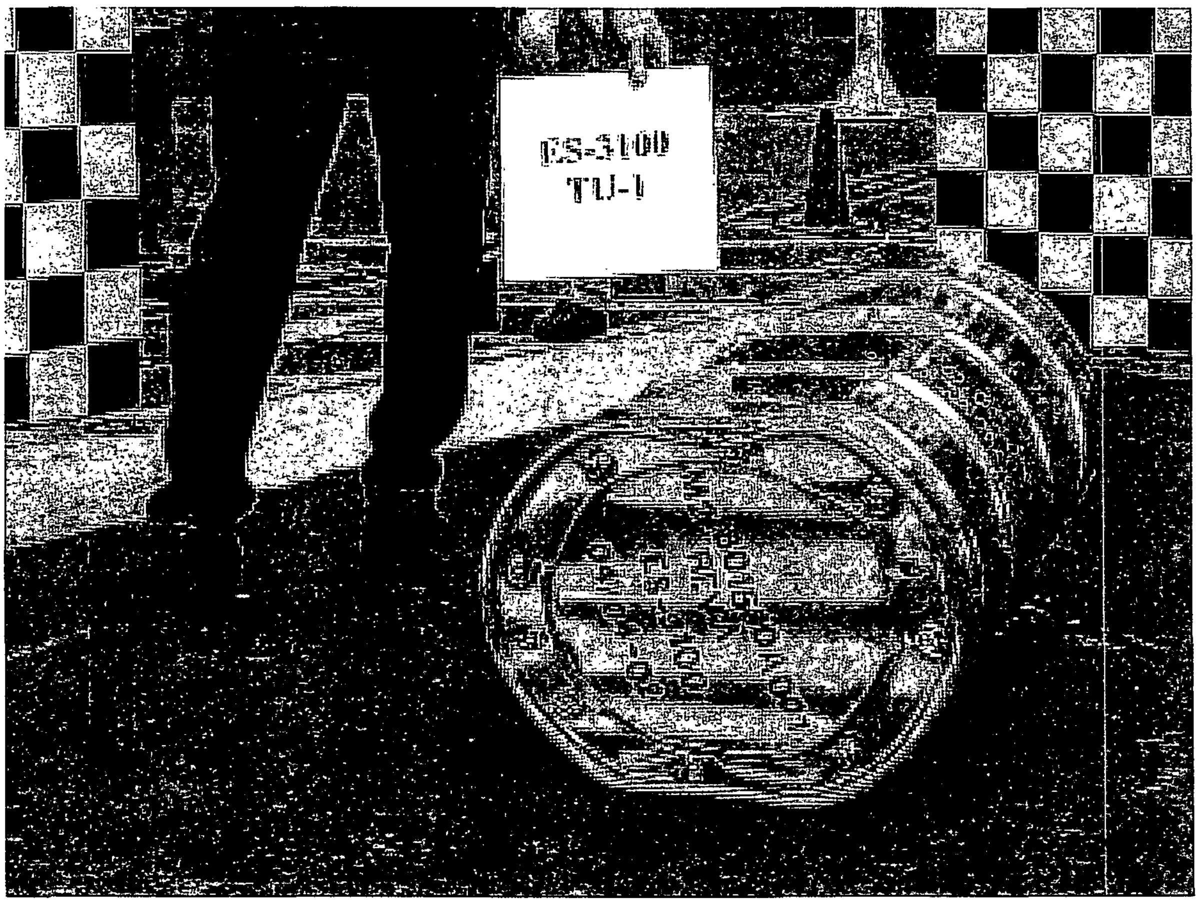


Fig. 2.14. Cumulative damage following 9-m crush on Test Unit-1.

Test Unit-2 (chilled package), weighing 202.8 kg (447 lb), was positioned in an horizontal attitude with the long axis of the drum parallel with respect to the drop pad. The damaged portion of the test unit, resulting from prior drop tests, was placed nearest the drop pad (0° mark facing down on pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 26.8°C (80.4°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the cumulative damage is shown in Tables 2.26, 2.27, and 2.28 in Sect. 2.7.1.2. Additional pictorials of damage are shown on Fig. 2.10.

Test Unit-3, weighing 203.7 kg (449 lb), was positioned in the same oblique attitude as previously drop tested from 9 m (30 ft). The long axis of the drum was at an oblique angle of 24.7° (desired angle was 24.6°) from the impact surface with the damaged portion of the lid in contact with the drop pad (0° mark in contact with pad). The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) with the center of gravity of both the plate and test unit in line at an ambient temperature of 30.5°C (86.9°F). The initial impact of the plate was with the edge of the drum bottom. A secondary contact occurred between the bottom drum rim and the impact surface. One drum stud was sheared from the test unit; however, the lid was still firmly attached to the drum, with no visible separation or rips. Therefore, the thermal barrier and neutron poison was maintained in position. Tables 2.40, 2.41, and 2.42 describe the measured damage which is recorded on Test Form 3 (Appendix 2.10.8). A photograph of the damage to Test Unit-3 is shown in Fig. 2.15.

Table 2.40. Recorded height damage to Test Unit-3 from the 9-m crush test

	0°	90°	180°	270°
Pre-crush height (in.)	40.63	43.25	43.75	43.38
Post 9-m crust test height (in.)	39.38	42.43	39.13	42.50

Table 2.41. Recorded flat contour damage to Test Unit-3 from the 9-m crush test

Axial measurement location	Flats width maximum pre crush (in.)	Flats width maximum post crush (in.)
Top of test unit	14.00	18.38
Bottom of test unit	0.00	17.88

Table 2.42. Recorded diametrical damage to Test Unit-3 from the 9-m crush test [Diameter (in.)]

Axial measurement location	0 to 180°		90 to 270°	
	Pre crush test	Post 9-m crush test	Pre crush test	Post 9-m crush test
Top false wire	19.25	19.25	19.19	19.06
Top rolling hoop	18.63	18.75	19.88	20.25
CG & top rolling hoop	19.13	19.25	19.38	19.75
CG rolling hoop	19.13	19.13	19.38	19.25
Bottom rolling hoop	19.13	19.13	19.38	19.75
Bottom false wire	19.13	18.00	19.25	19.38

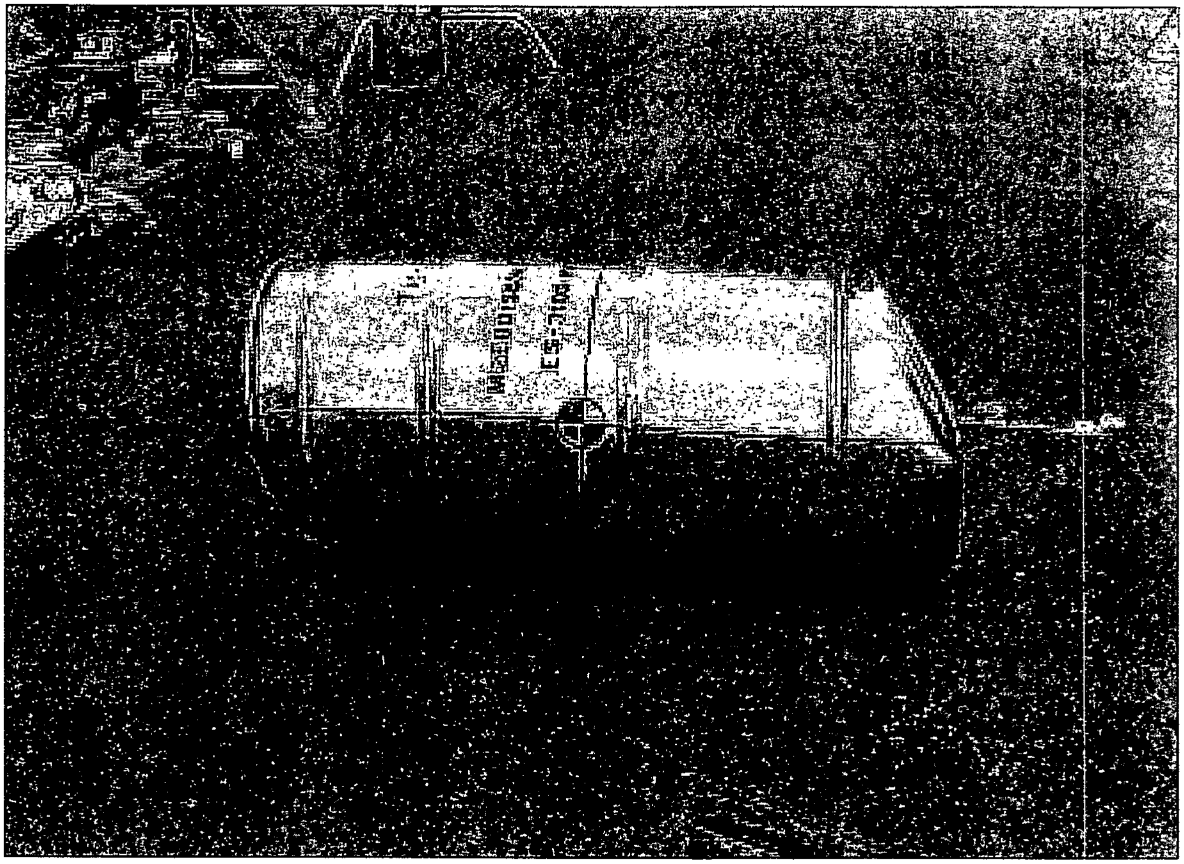


Fig. 2.15. Cumulative damage following 9-m crush test on Test Unit-3.

Test Unit-4, weighing 201.8 kg (445 lb), was positioned vertically with the previously damaged drum top in contact with the drop pad. The 500-kg (1100-lb) crush plate was dropped from 9 m (30 ft) and squarely contacted the bottom of the test unit. The center of the 500-kg (1100-lb) crush plate was positioned over the radial test unit's center of gravity, in this case over the center of the drum's bottom at an ambient temperature of 29.8°C (85.6°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.43 and 2.44 and a photograph is shown in Fig. 2.16.

Table 2.43. Recorded height damage to Test Unit-4 from the 9-m crush test

	0°	90°	180°	270°
Pre-crush height (in.)	43.00	43.13	42.88	42.63
Post 9-m crust test height (in.)	39.38	40.38	40.63	39.75

Table 2.44. Recorded diametrical damage to Test Unit-4 from the 9-m crush test [Diameter (in.)]

Axial measurement location	0 to 180°		90 to 270°	
	Pre crush test	Post 9-m crush test	Pre crush test	Post 9-m crush test
Top false wire	19.25	19.25	19.38	19.38
Top rolling hoop	19.13	20.00	19.88	20.13
CG & top rolling hoop	19.81	20.00	19.38	20.06
CG rolling hoop	19.13	19.43	19.25	19.50
Bottom rolling hoop	19.25	19.94	19.25	20.00
Bottom false wire	19.25	19.25	19.25	19.25

Fig. 2.16. Cumulative damage from 9-m drop and crush testing on Test Unit-4.

Test Unit-5, weighing 157.4 kg (347 lb), was positioned in a horizontal attitude with the damaged portion of the test unit, resulting from prior drop tests, placed on the drop pad (0° mark facing down on test pad). The 500-kg (1100-lb) crush plate was centered over the test unit's center of gravity and dropped from 9 m (30 ft) squarely onto the top false wire of the drum at an ambient temperature of 29.6°C (85.3°F). Following initial impact, the package bounced very little before landing on its side. No drum studs, nuts, or washers were lost due to the impact. The lid was still firmly attached to the drum, with no visible separation or rips; thus, the position of the thermal barrier and neutron poison was maintained. A summary of the resulting damage is shown in Tables 2.45, 2.46, and 2.47. Additional pictorials of damage are shown on Fig. 2.17. Since the length of the crush plate did not encompass the entire length of the test package; additional indentations are recorded on Test Form 3.

Table 2.45. Recorded height damage to Test Unit-5 from the 9-m crush test

	0°	90°	180°	270°
Pre-crush height (in.)	44.50	43.50	43.38	43.50
Post 9-m crust test height (in.)	45.00	43.50	43.75	43.88

Table 2.46. Recorded diametrical damage to Test Unit-5 from the 9-m crush tests [Diameter (in.)]

Axial measurement location	0 to 180°		90 to 270°	
	Pre crush test	Post 9-m crush test	Pre crush test	Post 9-m crush test
Top false wire	18.75	18.69	19.38	19.38
Top rolling hoop	18.75	17.13	19.38	19.63
CG & top rolling hoop	18.75	17	19.38	20
CG rolling hoop	18.75	16.75	19.25	20
Bottom rolling hoop	18.75	16.50	19.25	19.75
Bottom false wire	18.44	17.00	19.31	19.38

Table 2.47. Recorded flat contour damage to Test Unit-5 from the 9-m crush test

Axial measurement location	Flats width maximum @ 0° (in.)	Flats width maximum @ 180° (in.)
Top false wire	8.88	0.00
Top rolling hoop	8.50	12.50
CG & top rolling hoop	8.00	12.00
CG rolling hoop	8.75	11.38
Bottom rolling hoop	10.25	11.38
Bottom false wire	11.38	10.50

Fig. 2.17. Cumulative damage from 9-m drop and crush testing on Test Unit-5.

Conclusion. As noted in the discussion above, plastic deformation of the drum occurred in all test packages at the impacted areas. However, the position of the impact limiting material (Kaolite) and neutron poison material (BoroBond in the test packages) was maintained in all test packages. The maximum areal deformation along the side of the test packages was a flat measuring 31.75 cm (12.50 in.) wide at the drum's top rolling hoop and ending with a width of 26.67 cm (10.50 in.) at the drum bottom in Test Unit-5.

2.7.3 Puncture

Requirement. A free drop of 1 m (40 in.) from a position to obtain maximum damage onto the upper end of a solid, vertical, cylindrical, 15-cm (6-in.)–diameter mild steel bar mounted on an unyielding horizontal surface, is required by 10 CFR 71.73(c)(3). The bar must be ≥20 cm (8 in.) long with the top end rounded to 6-mm (0.25-in.) maximum radius. The long axis of the bar must be vertical.

Analysis. The five units previously dropped and crushed from 9-m (30 ft) [Sects. 2.7.1 and 2.7.2] were dropped from 1 m (40 in.) in accordance with 10 CFR 71.73(c)(3). The puncture bar was bolted to the steel plate of the inside drop pad surface at NTRC (see Sect. 2.6.7 regarding the indoor drop test pad). A description of the drop orientations and results are shown in Table 2.48. Figures 2.18 through 2.24 show the results of puncture testing.

Table 2.48. 1-m (40-in.) puncture drop test description and results

Test Unit	Test unit's long axis drop orientation	Axial and radial location from drum lid [a]	Recorded damage (indentation depth - in.)[b]	Photograph
1	Horizontal	Test Unit's CG (0° mark)	0.63	Fig. 2.18
1	Horizontal	8 in. down (180° mark)	0.38	Fig. 2.20
1	28° oblique from vertical	Drum lid's edge (90° mark)	three impact locations 1. 0.63 2. 0.38 3. 0.13	Fig. 2.18
1	40° oblique from vertical	In line with test unit's CG (270° mark)	two impact locations 1. 0.75 2. 0.13	Fig. 2.19
2	Horizontal	Test Unit's CG (0° mark)	0.13	Fig. 2.21
3	24.6° oblique from vertical	In line with test unit's CG (270° mark)	two impact locations 1. Additional flattening of lid 2. 0.88	Fig. 2.22
4	Vertical	Center of drum's lid & CG	0.13	Fig. 2.23
5	Horizontal	8 in. down (0° mark)	0.13	Fig. 2.24

[a] See detailed description of test units in Sect. 5.4.3 of ORNL/NTRC-013.
[b] For detailed description of damaged locations, see Test Form 4 for Test Units 1, 3, 4, and 5 and Test Form 3 for Test Unit-2.

Conclusion. Although all test units were deformed by this puncture test, no drum surfaces were breached, thereby maintaining the integrity of the thermal barrier and neutron poison.

2.7.4 Thermal

Requirement. Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent and in sufficiently quiescent ambient conditions to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 min, or any other thermal test that provides the equivalent total heat input to the package and that provides a time-averaged environmental temperature of 800°C (1475°F). The fuel source must extend horizontally at least 1 m (40 in.) but may not extend more than 3 m (10 ft) beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in.) above the surface of the fuel source. For purposes of calculation, the surface absorptivity must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction must be allowed to proceed until it terminates naturally.

Analysis. The five test units previously subjected to both NCT and HAC drop testing were thermal tested in accordance with 10 CFR 71.73(c)(4). To determine the maximum temperatures reached during thermal testing, temperature indicating patches were placed at various locations throughout the test packages at assembly. The temperature range for each patch used is identified in Table 2.49. When the temperature of an indicator was reached, the color would change to black (i.e., blackout temperature). The range of possible blackout temperatures of the patches was from 51.67 to 260°C (125 to 500°F). For Test Units-1 through -5, Table 2.49 defines the number and location of the temperature indicating patches.

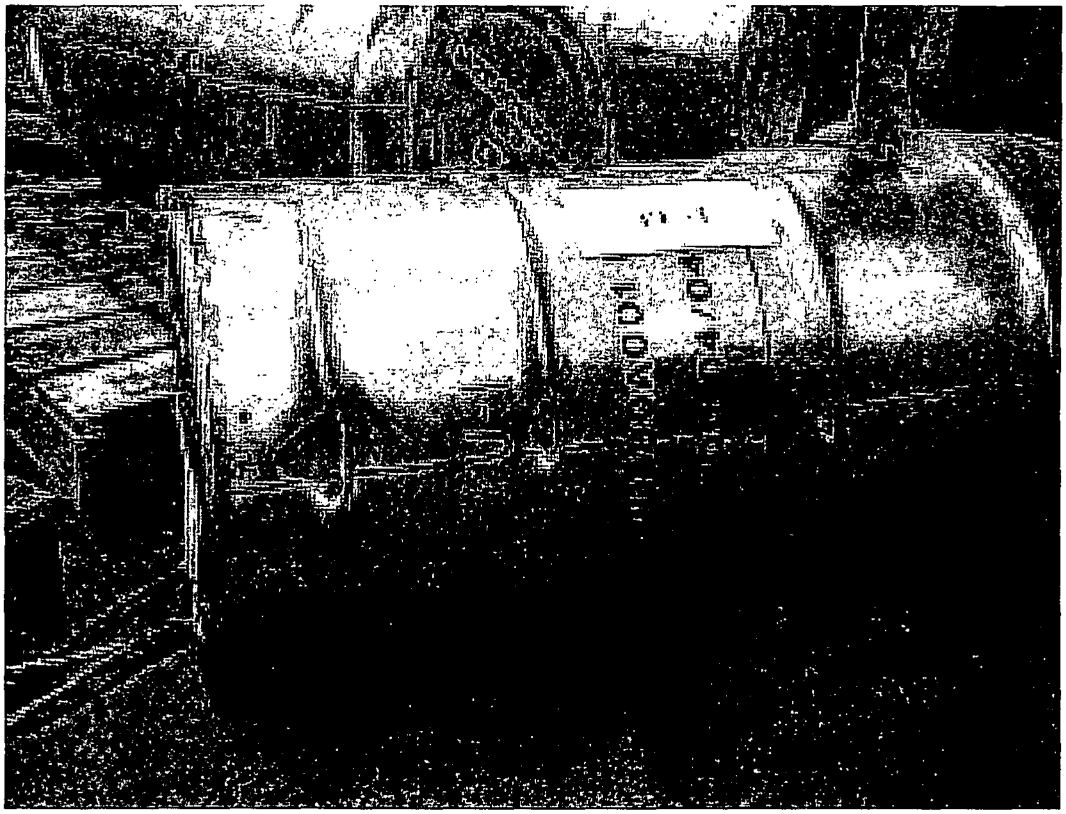


Fig. 2.18. 28° oblique and horizontal puncture tests on Test Unit-1.

Fig. 2.19. 40° oblique puncture test on Test Unit-1.

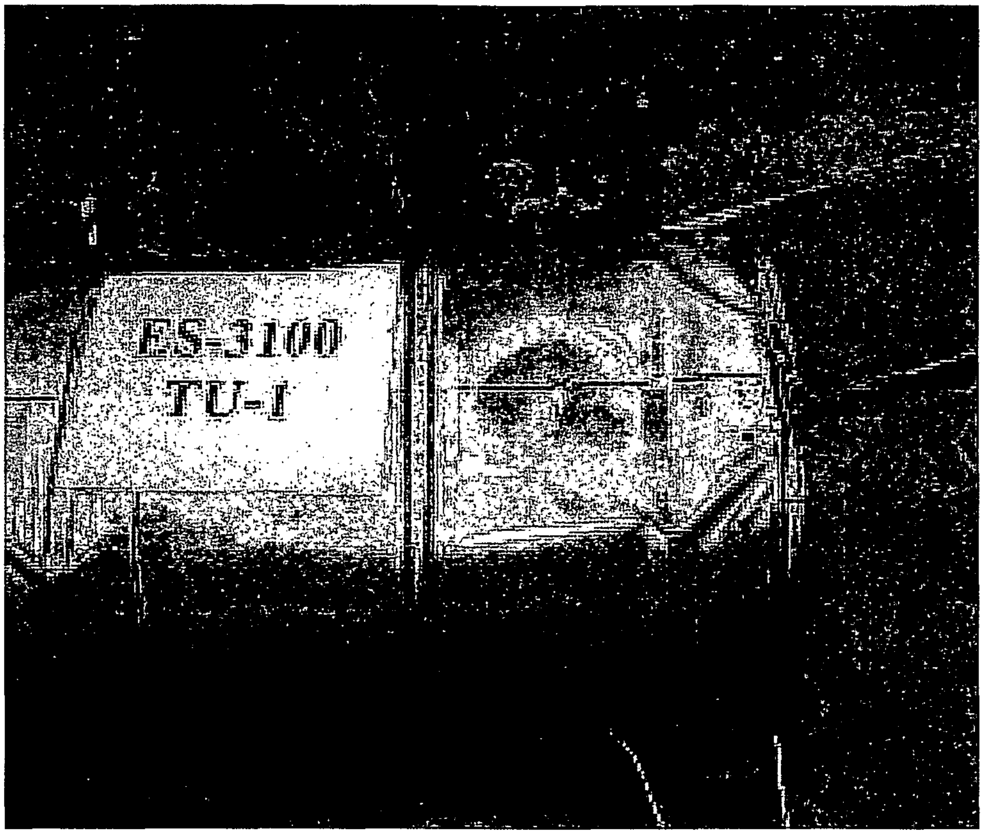


Fig. 2.20. Horizontal puncture test over Test Unit-1's containment vessel flange.

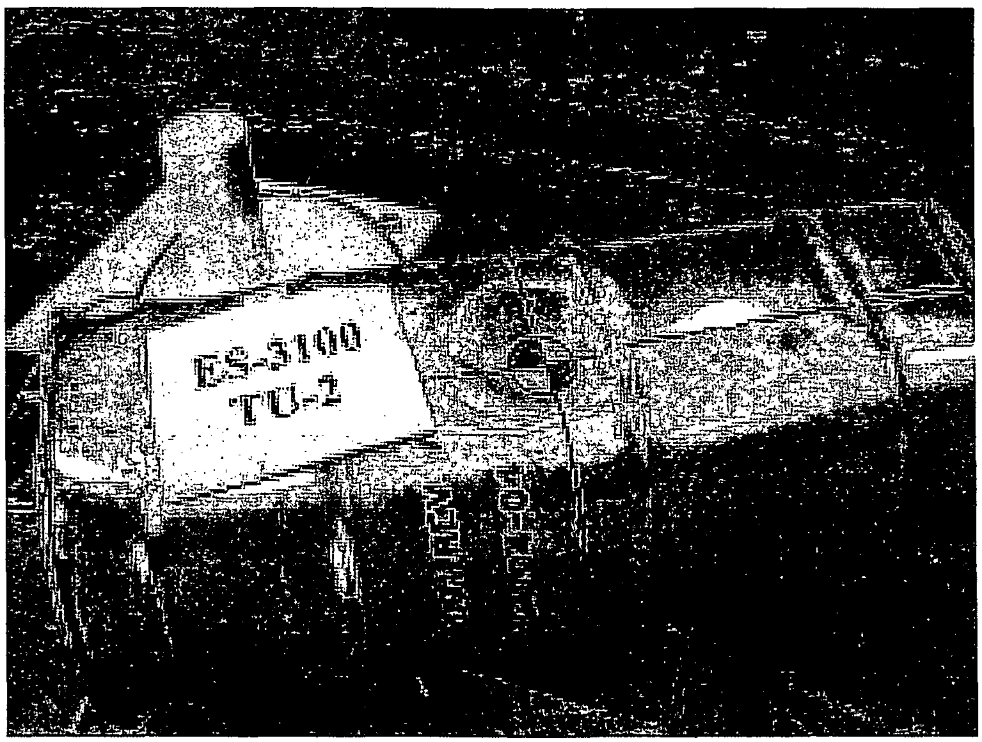


Fig. 2.21. Horizontal CG puncture test on Test Unit-2.

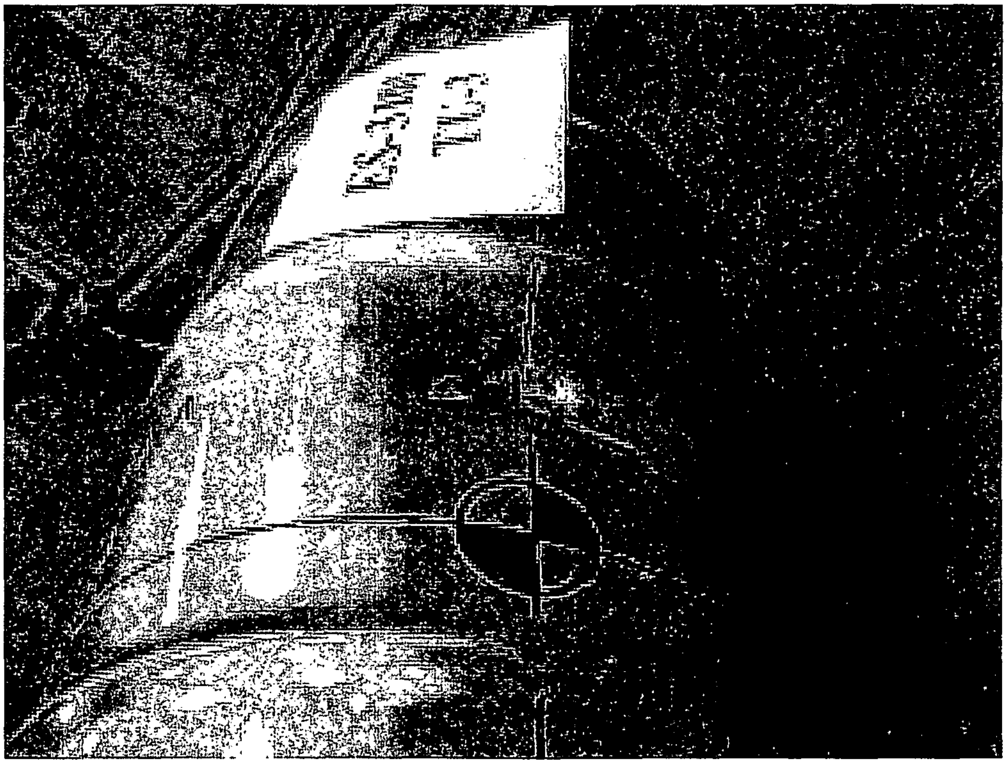


Fig. 2.22. 24.6° oblique puncture test on Test Unit-3.

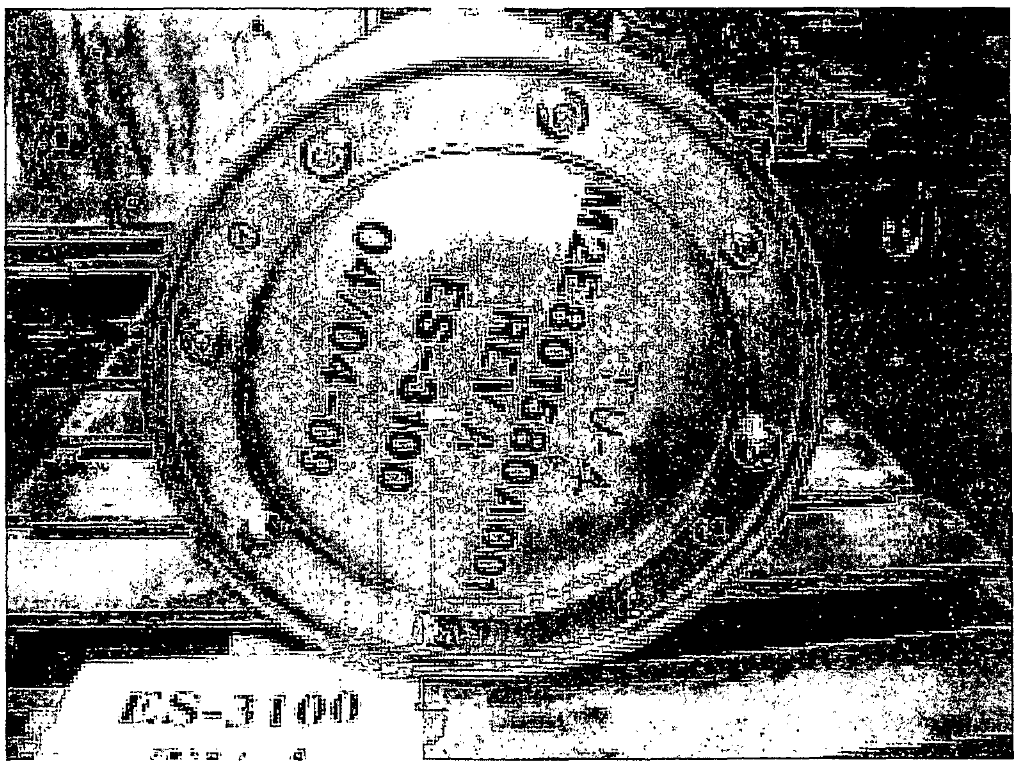


Fig. 2.23. Vertical puncture test on Test Unit-4.

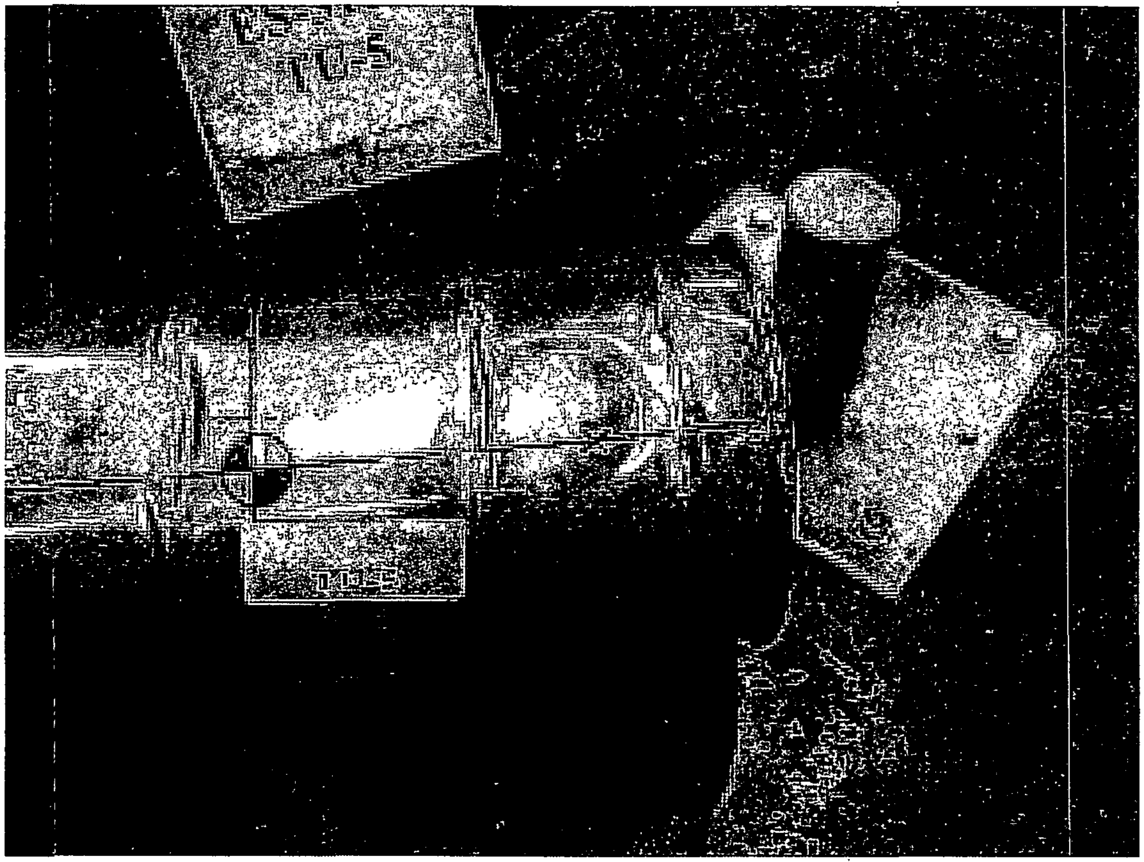


Fig. 2.24. Horizontal puncture test over Test Unit-5's containment vessel flange.

Table 2.49. Thermax temperature indicating patches for test units

Patch Location	Internal surface	External surface	Temperature range °C (°F)	Test report figure (ORNL/NTRC-013)
Inner liner of drum assembly		8 (Full Range) 10 (5B & 5C)	52 to 260 (125 to 500) "B" 77 - 127 (171-261) "C" 132 - 182 (270-360)	5.3
Top plug weldment		4 (Full Range)	52 to 260 (125 to 500)	5.31
Containment vessel body flange	8 (4B & 4C)	8 (4B & 4C)	"B" 77 - 127 (171-261) "C" 132 - 182 (270-360)	5.28
Containment vessel body (end cap and cylinder)		5 (B)	"B" 77 - 127 (171-261)	5.28
Containment vessel sealing lid	4 (B)	4 (B)	"B" 77 - 127 (171-261)	5.29
Test mock-up components		6 (B)	"B" 77 - 127 (171-261)	5.26 & 5.27

Prior to the beginning of the thermal test, the No. 3 furnace at Timken Steel Company in Latrobe, Pennsylvania, 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.

A total of 18 thermocouples was installed on the furnace surfaces and on the test package support stand. (Appendix 2.10.7) All units were tested in a horizontal attitude with the end of the package facing the right and left side walls of the furnace. The test units were thermally tested with the 0° mark on the drum facing the floor of the furnace.

Each test unit was preheated to over 37.78°C (100°F) by placing the packages in an environmental chamber. The environmental chamber was heated by a torpedo-type kerosene space heater controlled by a mechanical bulb thermostat with a control range of 100°F to 200°F. The environmental chamber is a welded steel frame with fiberglass insulation panels. It was heated from the bottom with four floor register vents located around the perimeter and an 8 in. manual dampened center venting stove pipe. The setpoint temperature of the environmental chamber was monitored and adjusted for the duration of the preheat cycle. Initially, the thermostat was set to 66°C (150°F) for ~23 h. The thermostat set point was then reduced to ≥43°C (110°F) for the remainder of the preheat cycle. All packages were preheated for at least 47 h.

Six thermocouples were attached to the exterior surface of each test package after preheating. Metal retainer clips were welded to the drum to hold the thermocouples in place. The thermocouple tips were inserted underneath the metal clips and the wire was wrapped around the metal clip. To eliminate any radiant heat exchange between the thermocouples and the furnace walls, the tips and metal clips were covered with a ceramic coating.

No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher. All packages were placed in the preheated furnace on the support stand positioned with the long axis horizontal, the package lid facing toward a furnace side wall and oriented as described above. These packages were exposed to the radiation environment for a minimum of 30 min after all functioning furnace thermocouples, and at least five of the six test package exterior surface thermocouples reached a temperature of 800°C (1475°F). During the testing, the thermocouple temperature data were recorded every 15 s.

A minimum of 24 h prior to the beginning of all testing, the furnace was turned on with a set-point temperature of 871°C (1600°F). After each test, the furnace was allowed to reheat for a minimum of 45 min after obtaining the setpoint temperature before testing the next unit. The furnace control temperature data recorder ran continuously for the duration of the preheat. No test package was loaded into the furnace until all functioning thermocouples on the furnace walls and support stand had a reading of 800°C (1475°F) or higher.

Each test package was removed from the furnace and placed in an area where it was not exposed to artificial cooling. As the furnace door was opened for each test unit, smoking or flaming was visible from the TID lug hole at 0°. Flaming continued on some packages for 22 minutes and smoking continued up to one hour on others. All of the packages were allowed to cool naturally to room temperature. The post-thermal test weights of each unit were recorded on Test Form 1 of the test report. (Appendix 2.10.8) The drums were disassembled, and the damage was photographed. The post-thermal test weight of each loaded containment vessel was also recorded. Each package was visually inspected, and the condition of the package and any observations were recorded.

After the containment vessels were removed from Test Units 1 through 5, two different leak tests were performed on each containment vessel. An operation leak test was conducted between the O-rings using a CALT5 leak tester. Following this operational leak test, a full body helium leak test was conducted. Details of these leak tests are provided in the test report (Appendix 2.10.7) and the results are summarized in Table 2.23. All five containment vessels were then removed from the drum assembly and immersed under a head of water of at least 0.9 m (3 ft) in a horizontal position for a period of ≥8 h. Following the immersion test of 10 CFR 71.73(c)(6), the containment boundary of Test Units-1 through -5 were opened to remove the contents, gather available data and look for signs of water in-leakage. No water in-leakage was detected in any of the units.

The blackout temperatures on the surface of all five containment boundaries, inner liners, and mock-up components used in the test packages are given in the test report (Test Form 5 for each test unit). Maximum blackout temperatures recorded on the surface of all test units are tabulated in Table 2.50. These values and temperature adjustments are discussed in Sect. 3.5.3.

Conclusion. All five test packages were intact following the 30-min exposure to the high-temperature thermal environment as required in 10 CFR 71.73(c)(4). Examination during disassembly showed that the containment boundary surfaces, flanges, fasteners, sealing surfaces, and O-rings were not damaged by the thermal testing. All five containment boundary assemblies met the subsequent 0.9-m (3-ft) water immersion test and maintained a full-body helium leak rate $\leq 2.0 \times 10^{-7}$ cm^3/s. Following compliance testing, minor changes were made to the mid liner, and the neutron poison was changed from BoroBond4 to Cat 277-4. In order to evaluate the impact of these changes, extensive analytical drop simulations were utilized. A detailed description of the models, material properties, and drop orientations evaluated is shown in Appendix 2.10.2. Results comparing structural deformation and maximum strains in the various material of construction are shown in Sect. 2.7.8. Based on the HAC analytical structural deformation results shown in Sect. 2.7.8, similar compliance test results would be expected had testing been conducted on packages employing the new proposed Cat 277-4 neutron poison. Therefore, the requirements of 10 CFR 71.73(c)(4) were satisfied, and containment was maintained.

2.7.4.1 Summary of pressures and temperatures

The ES-3100 shipping packages will typically be loaded at an ambient temperature and absolute pressure of ~25°C (77°F) and 101.35 kPa (14.70 psi), respectively. If the temperature of the package increases during shipment due to external temperature or solar insolation, the drum will not pressurize because four ventilation holes are drilled near the top of the drum, and the drum is not sealed at the drum lid–flange interface. The containment boundary is sealed at assembly. The internal pressure will increase due to transport temperatures, solar insolation (Sect. 3.4.1), decay heating, and the temperatures during HAC (Sect. 3.5.3). Temperature and pressures are summarized in Tables 3.21 and 3.11.

Table 2.50. **Maximum HAC temperatures recorded on the test packages' interior surfaces**

Temperature patch location[a]	ES-3100 Test Unit				
	1	2	3	4	5
	°C (°F)	°C (°F)	°C (°F)	°C (°F)	°C (°F)
Top plug bottom	149 (300)	163 (325)	177 (350)	177 (350)	177 (350)
Inner liner					
Flange step wall	135 (275)	163 (325)	135 (275)	135 (275)	135 (275)
BoroBond4 step	107 (225)	135 (275)	107 (225)	177 (350)[b]	121 (250)
CV body wall high	99 (210)	99 (210)	99 (210)	99 (210)	104 (219)
CV body wall middle	99 (210)	93 (199)	116 (241)[b]	93 (199)	99 (210)
Bottom flat portion	104 (219)	99 (210)	99 (210)	127 (261)	110 (230)
Containment boundary					
Lid (external top)	116 (241)	110 (230)	116 (241)	127 (261)	127 (261)
Lid (internal)	104 (219)	104 (219)	110 (230)	110 (230)	116 (241)
Flange (external)	116 (241)	110 (230)	110 (230)	116 (241)	121 (250)
Flange (internal)	104 (219)	99 (210)	116 (241)[b]	104 (219)	116 (241)
Body wall mid height	99 (210)	88 (190)	99 (210)	82 (180)	93 (199)
Bottom end cap (center)	99 (210)	99 (210)	88 (190)	110 (230)	99 (210)
Mock-up					
Side top	82 (180)	77 (171)	77 (171)	77 (171)	99 (210)
Side middle	77 (171)	77 (171)	77 (171)	77 (171)	93 (199)
Side bottom	77 (171)	77 (171)	77 (171)	77 (171)	88 (190)

[a] Refer to figures for exact locations and to Test Form 5 in the test report for recorded values. (ORNL/NTRC-013)
[b] Temperature indicating patch may have been damaged due to impact with surrounding structure. See Test Form 5 in ORNL/NTRC-013 for additional information.

The maximum HAC internal absolute pressure in the containment boundary of the ES-3100 has been calculated to be 507.63 kPa (73.625 psia). This predicted pressure is based on a conservative maximum adjusted average gas temperature of 123.85°C (254.93°F) as shown in Sect. 3.5.3 and Appendix 3.6.5.

2.7.4.2 Differential thermal expansion

The drum, inner liner, and containment vessel are all constructed of type 304 or 304L stainless steel. Because of design clearances used during assembly, radial and vertical expansion among these components will not cause any interferences or thermally induced stresses. Due to similarities of the coefficient of thermal expansion between type 304/304L and the containment vessel closure nut (ASTM A-479 and ARMCO Nitronic 60), the compression of the O-rings and the closure nut and containment vessel thread load do not change appreciably during the temperature excursion from 25°C (77°F) to the maximum adjusted containment vessel temperature of 152.22°C (306.0°F) [Sect. 3.5.3].

The Kaolite 1600 insulation and Cat 277-4 neutron poison are poured and cast in place during the fabrication of the drum assembly weldment (Drawing M2E801580A002, Appendix 1.4.8). This process produces a zero gap between the insulation and the bounding drum and inner liner and zero gap between the neutron poison and the mid and inner liners. Because of differences in coefficients of thermal expansion, some radial and axial interferences are expected from thermal growth of the liners. These radial and axial interferences have been addressed by the HAC thermal test. The results show that the stresses induced are minimal and do not reduce the effectiveness of the drum assembly.

Since there are ample clearances between the various size convenience containers and HEU contents, no induced thermal stresses from differences in coefficient of thermal will exist.

2.7.4.3 Stress calculations

The temperature gradient on the containment boundary was essentially uniform from top to bottom during the thermal tests (Table 2.50). The gradient around the periphery of the six test units was also essentially uniform and similar to the vertical gradient. As noted in the ES-3100 test report, the temperatures recorded on the containment vessels of all the test units were fairly uniform, both vertically and circumferentially. The maximum temperature variation on the containment vessels was ~50°F (from the test temperatures reported in Table 2.50). No damage would be expected on the containment vessel from thermal stresses resulting from a temperature differential of this magnitude. This conclusion is based on the guidelines given in the *ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (ASME B&PVC, Sect. III, Paragraph NB-3213.13). This paragraph further states that there are two types of thermal stresses: general thermal stress and local thermal stress. An example of a general stress is that produced by an axial temperature distribution in a cylindrical shell (ASME B&PVC, Paragraph NB-3213.9). This general stress is further classified (Paragraph NB-3213.9) as a secondary stress (that is, a normal stress or a shear stress developed by the constraint of adjacent materials or by self-constraint of the structure) [ASME B&PVC, Paragraph NB-3213.9]. Paragraph NB-3213.9 further states that the basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur, and failure from a single application would not be expected. An example of a local thermal stress is a small hot spot in the wall of a pressure vessel (ASME B&PVC, Paragraph NB-3213.13). Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses are considered only from a fatigue standpoint. Fatigue will not result from a one-time cyclic event such as an accidental fire.

The principal effect of the elevated temperature on stress levels is caused by the increase in the internal pressure. The calculated stresses as shown in Table 2.51 were determined by multiplying the stress at the design conditions (Appendix 2.10.1) by a factor equal to the ratio of operating pressures to design pressures and adding any contribution from the closure nut preload. This methodology is based on the application of linear elastic material behavior. As shown in Sect. 2.7.4.4, all stresses in the containment boundary components (based on nominal dimensions for the components) are well below the *ASME Boiler and Pressure Vessel Code* allowable stress intensity limits.

2.7.4.4 Comparison with allowable stresses

As noted in Sect. 2.7.4.3, the differential stresses resulting from temperatures recorded during HAC are negligible. Also, as shown in Table 2.51, stresses of this low magnitude do not affect the adequacy of the packaging. Corresponding calculated stress regions are shown in Fig. 2.1.

2.7.5 Immersion—Fissile Material

Requirement. In those cases for which water leakage into the containment boundary has not been assumed for criticality analysis, the specimen must be immersed under a 0.9-m (3-ft) head of water in an attitude for which maximum leakage is expected, as required by 10 CFR 71.73(c)(5).

Table 2.51. HAC ES-3100 containment boundary stress compared to the allowable stress [a]

Stress locations shown in Fig. 2.1	Thermal condition 10 CFR 71.73 (c)(4) containment boundary stress @406.27 kPa (58.925 psi) gauge & 123.85°C (254.93°F) kPa (psi)		Immersion condition 10 CFR 71.73 (c)(6) containment boundary stress @−150 kPa (−21.76 psi) gauge & −2.22°C (28°F) kPa (psi)		Allowable stress (AS)
	kPa (psi)	M.S.	kPa (psi)	M.S.	kPa (psi)
Top flat portion of sealing lid (center of head)	4.003×10^3 (580.5)	32.1	1.478×10^3 (214.4)	88.6	1.324×10^5 (19,200)[b]
Closure nut ring (away from threaded portion)	7.030×10^4 (10,196)	5.5	4.246×10^4 [f] (6158)	9.8	4.571×10^5 (66,300)[c]
Top flat head (sealing surface region)	2.385×10^4 (3460)	10.1	1.665×10^4 [f] (2415)	14.9	2.648×10^5 (38,400)[c]
Cylindrical section (middle)	1.160×10^4 (1683)	6.6	4.285×10^3 (621.5)	19.6	8.825×10^4 (12,800)[d]
Cylindrical section (shell-to-flange interface)	2.125×10^4 (3083)	11.5	1.238×10^4 (1795.3)	20.4	2.648×10^5 (38,400)[c]
Cylindrical section (shell-to-bottom interface)	2.976×10^4 (4317)	7.9	1.099×10^4 (1594.2)	23.1	2.648×10^5 (38,400)[c]
Body flange threads load, kg (lb)	1571×10^3 (3464)	12.1	9.072×10^2 [f] (2000)	21.6	2.053×10^4 (45266)[e]
Body flange thread region (under cut region)	4.562×10^4 (6594)	4.8	2.397×10^4 [f] (3476)	10	2.648×10^5 (38,400)[c]
Flat bottom head (center)	2.802×10^4 (4064)	3.7	1.035×10^4 (1500.7)	11.8	1.324×10^5 (19,200)[b]
Closure nut thread load, kg (lb)	1.571×10^3 (3464)	21.6	9.072×10^2 [f] (2000)	38.1	3.545×10^4 (78154)[e]

[a] Calculated stresses were determined by multiplying the stress at the design conditions (Appendix 2.10.1) by a factor equal to the ratio of operating pressures to design pressures (independent of pressure direction) plus contribution from preload. Allowable stress values are taken from Table 2.5.
[b] Stress interpreted as the sum of $P_l + P_b$; allowable stress intensity value is $1.5 \times S_m$.
[c] Stress interpreted as the sum of $P_l + P_b + Q$; allowable stress intensity value is $3.0 \times S_m$.
[d] Stress interpreted as the primary membrane stress (P_m); allowable stress intensity value is S_m.
[e] Allowable shear capacity is defined as $0.6 \times S_m \times$ thread shear area. Thread shear area = 38.026 cm² (5.894 in.²).
[f] Stress and shear load in these areas are dominated by the 162.7 ± 6.8 N·m (120 ± 5 ft-lb) preload.

Analysis. The containment vessels for the ES-3100 test packages (Units-1 through -5) were removed from their respective drum assemblies following the thermal tests described in Sect. 2.7.4. After examination for damage (distortion, warpage, heating), the volume between the O-rings was pressurized, and the O-ring seals were leak checked in accordance with the CALT5 manufacturer's instructions manual using the CALT5 leak tester. Following the O-ring cavity check, the containment vessel lids were drilled and tapped for a full-body helium leak check. The seals remained functional on all vessels, and the integrity of the containment vessel structure was maintained (indicated by a helium leak rate $\leq 2.0 \times 10^{-7}$ cm^3/s). Following these leak tests, each unit was then submerged under a 0.9-m (3-ft) head of water for at least 8 h. No water leakage into the vessel was seen in any of the test units. The results of this test for each unit are recorded on the data sheet of Procedure TTG-PRF-14 shown in the test report. (Appendix 2.10.8) It should be noted that the criticality analysis does assume water leakage into the ES-3100 containment vessel; however, the 0.9-m (3-ft) immersion tests were performed anyway.

2.7.6 Immersion—All Packages

Requirement. A separate, undamaged specimen must be immersed under water at a pressure equivalent to a 15-m (50-ft) head of water, as required by 10 CFR 71.73(c)(6). This requirement may be satisfied by an external pressure of 150 kPa (21.7 psi) gauge.

Analysis. Immersion under a 15-m (50-ft) head of water would result in water entering the drum because the plastic plugs covering the four ventilation holes could fail, and the drum/lid flange is not gasketed. The ES-3100 containment boundary has been designed and tested for an external pressure of 150 kPa (21.7 psi) gauge and an internal gauge pressure of 699.82 kPa (101.5 psi), using nominal dimensions for all boundary components. Each containment vessel design incorporates an O-ring seal of verified integrity to provide assurance that no water will penetrate the containment boundary. The containment boundary of Test Unit-6 was subjected to this 15-m (50-ft) water immersion test. No visual signs of water leakage into the containment boundary were recorded.

2.7.7 Deep Water Immersion Test (for Type B Packages Containing More than 10^5 A_2)

The amount of A_2s proposed for transport is ~293.99. Therefore, the deep water immersion test is not applicable.

2.7.8 Summary of Damage

After testing five full scale ES-3100 test packages under HAC, the drum, drum lid, and top plug were damaged as expected. The containment boundary flange, O-ring grooves, and closure nut were not damaged. Plastic deformation occurred in the five drum assemblies in the impact areas from the 1.2-m and 9-m (30-ft) drop, crush and subsequent puncture tests. No breaks were noted in the drum assembly, and no insulation was exposed. The resultant damage did not reduce the effective center-to-center package spacing to a point of criticality concern (Sect. 6).

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 diameter of the step in the inner liner for the containment vessel 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 containment vessel 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. Temperature dependent material properties were used in the analysis. The results of the structural deformation from compliance testing, drop simulation using BoroBond4 and drop simulations using Cat 277-4 material are presented in the following tables and figures. The analytical structural deformation results shown in Tables 2.52 through 2.61 are nearly identical for the two neutron poisons. The analytical results are also well representative of the results recorded during compliance testing as depicted in Figs. 2.25 through 2.30. Analytical strain prediction in the structural components are also compared for the two neutron poisons. Although there are minor differences between the compliance testing and drop simulations, the overall magnitude of the strains is 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 71.71 and 71.73, and the results of compliance testing would be analogous. Some of the test units lost approximately 0.45 kg (1 lb) of their gross weight due to boiling off of the water trapped in the refractory and BoroBond4 materials (Table 2.62).

Assuming all water loss is from the neutron poison, the BoroBond4 material lost ~ 9.4% of its water content. Using the temperature data recorded during HAC testing shown in Table 2.50 and applying the temperature adjustments discussed in Sect. 3.5.3, the average temperature of the neutron poison would be ~150°C (302°F). Since the ES-3100 test units were not fabricated packages with Cat 277-4, thermogravimetric analysis (TGA) was used to compare the neutron poison's propensity to lose water. The results of this analysis are shown in Appendix 2.10.4 (Thompson, *Summary of TGA Testing*). Samples of both BoroBond4 and Cat 277-4 were TGA tested, and the results were compared at 150°C (302°F). The BoroBond4 samples lost ~ 61.6% of their original water content. The dry Cat 277-4 lost a maximum of only 6.61%. The BoroBond4 TGA samples lost ~6.5 times the amount of water lost by the ES-3100 test units during HAC compliance testing. Assuming comparable results would be expected for the Cat 277-4 material due to similarity in the structural configuration, installation methodology, and LS-Dyna drop simulation structural deformation results, the Cat 277-4 water loss would be only 1.02%. Criticality safety analysis assumes a greater percent loss; therefore, additional conservatism is being applied in this SAR.

The maximum blackout temperature recorded adjacent to the O-rings during testing was 127.22°C (241°F) [Table 2.50]. Using the adjustments discussed in Sect. 3.5.3, the maximum adjusted temperature at the containment boundary O-rings during shipment under HAC was calculated to be 141.22°C (286.2°F). The normal operating temperature for these O-rings is −40 to 150°C (−40 to 302°F) as shown in Table 2.15. Therefore, containment will be maintained during HAC.

Following the thermal test, all five containment boundaries were subjected to leak testing of the O-ring cavity as well as the full-body helium leak check. To verify the entire containment boundary, all test units were drilled and tapped for a helium leak check using the procedure documented in the test report. (Appendix 2.10.7) The procedure consisted of creating a near vacuum inside the containment vessel and supplying a helium environment around the exterior of the assembly. The maximum recorded helium leak rate for any of these containment vessels was 2.0×10^{-7} cm^3/s as documented after 20 min of leak checking. This procedure measures leakage in the opposite direction to leakage from the vessel. It

Table 2.52. Diametrical damage comparison of Test Unit-1 with analytical predictions [Diameter (in.)]

	0 to 180°			90 to 270°		
Axial measurement location	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	15.63	15	14.9	20.63	20.7	20.7
Top rolling hoop	16	15.3	15.1	20.44	20.8	20.8
CG & top rolling hoop	16.25	15.9	15.7	20.25	20.6	20.7
CG rolling hoop	16.5	16.4	16.2	19.88	20.1	20.4
Bottom rolling hoop	18.25	18.3	18.1	19.5	19.6	19.8
Bottom false wire	17.81	18.1	18	19.25	19.4	19.4

Table 2.53. Flat contour damage comparison of Test Unit-1 with analytical results

Axial measurement location	Flats width @ 0° (in.)			Flats width @ 180° (in.)		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	9	10.5	10.5	8.5	10.5	10.9
Top rolling hoop	10	11	11	10	11	11
CG & top rolling hoop	10	10.1	10.1	10.13	10.1	10.1
CG rolling hoop	9	8.4	8.4	10.63	10.1	10.1
Bottom rolling hoop	8.25	7.6	7.6	---	0	0
Bottom false wire	9,88	10.1	10.1	---	0	0

Fig. 2.25. Visual comparison of the cumulative damage on the crush side surface after the three drop tests (from top to bottom: Test Unit-1, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.54. Cumulative analytical 12° slapdown drop tests maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)			
		Offset crush		Centered crush	
		Model with BoroBond	Model with Cat 277-4	Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0457	0.0564	0.0741	0.0643
CV lid	Type 304L stainless steel	0.0005	0.0013	0.0006	0.0018
CV closure nut	A-479 nitronic 60	0.0000	0.0001	0.0003	0.0000
Angle	Type 304 stainless steel	0.1045	0.1070	0.0917	0.0944
Drum	Type 304 stainless steel	0.3972	0.3920	0.3537	0.3443
Drum bottom	Type 304 stainless steel	0.2877	0.2879	0.2919	0.3000
Liner	Type 304 stainless steel	0.2702	0.2060	0.2363	0.2846
Lid	Type 304 stainless steel	1.0797	0.9689	1.0795	0.5828
Lid stiffener	Type 304 stainless steel	0.0838	0.0894	0.0303	0.0288
Drum lid studs	Type 304 stainless steel	>0.57	0.4018	0.3174	0.2390
Lid hex nut	Silicon bronze - C65100	0.0086	0.0028	0.0000	0.0000
Drum washer	300 series stainless steel	0.1003	0.0790	0.0597	0.0775
Top plug weldment	Type 304 stainless steel	0.2715	0.2665	0.1636	0.1644

Table 2.55. Diametrical damage comparison of Test Unit-2 with analytical predictions [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	17.63	18.1	18	19.81	19.6	19.6
Top rolling hoop	17.38	16.6	16.6	19.75	19.75	20.1
CG & top rolling hoop	17	16.5	16.5	20	20	20.4
CG rolling hoop	16	16.3	16.3	20.25	20.25	20.5
Bottom rolling hoop	15.5	16.1	16.1	20.13	20.13	20
Bottom false wire	18	17.6	17.6	19.25	19.38	19.4

Table 2.56. Flat contour damage comparison of Test Unit-2 with analytical predictions

Axial measurement location	Flats width @ 0° (in.)			Flats width @ 180° (in.)		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	8	9.2	9.2	6.25	0	0
Top rolling hoop	9	8.4	9.3	8.88	10.1	10.1
CG & top rolling hoop	10.13	8.4	8.4	9.63	8.4	9.3
CG rolling hoop	9.88	9.3	9.3	12	9.3	9.3
Bottom rolling hoop	9.88	9.3	9.3	14.88	10.1	10.1
Bottom false wire	9.38	10.1	10.1	0	0	0

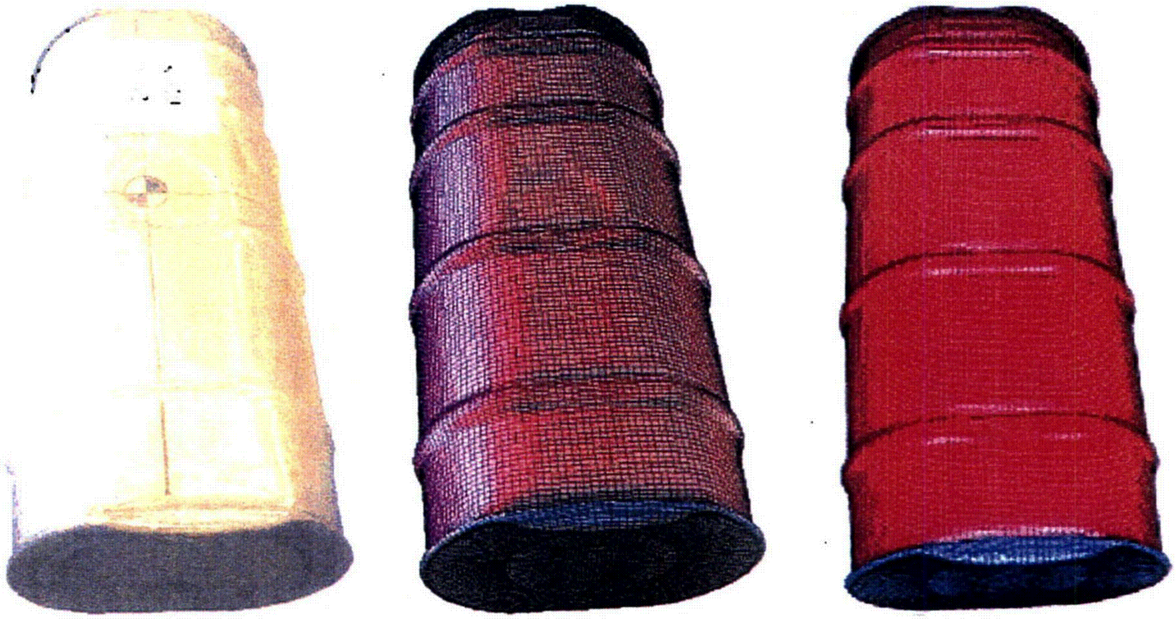


Fig. 2.26. Visual comparison of the cumulative damage on the rigid surface side after the four drop tests (from left to right: Test Unit-2, analytical results with BoroBond, analytical results with Cat 277-4).

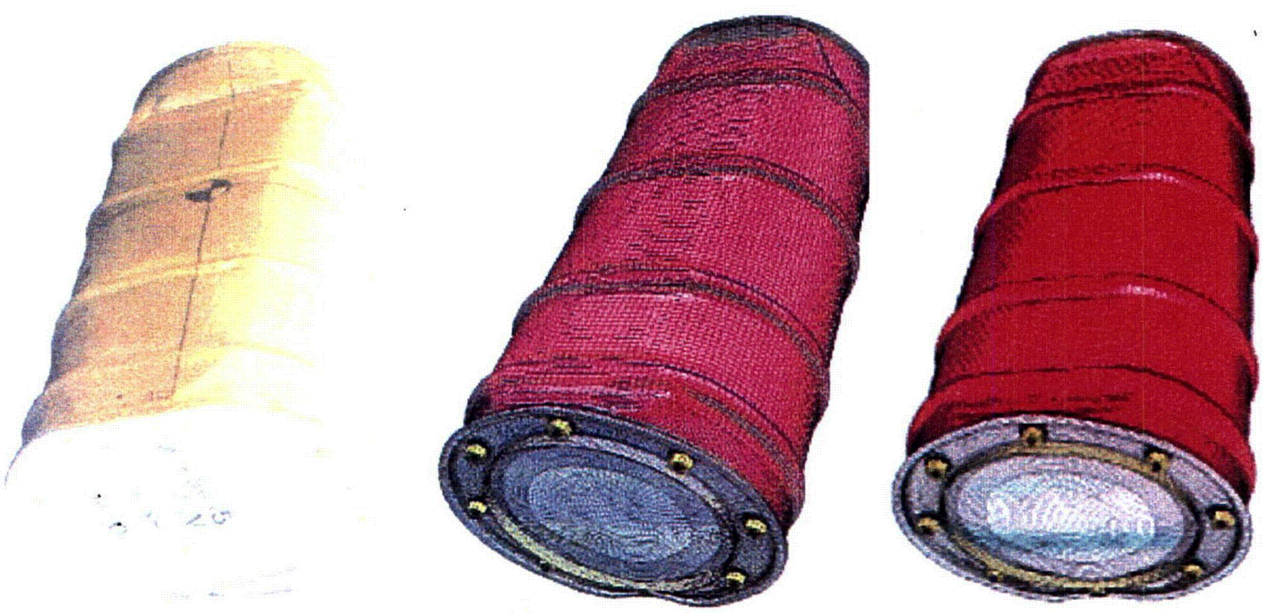


Fig. 2.27. Visual comparison of the cumulative damage on the crush plate side after the three drop tests (from left to right: Test Unit-2, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.57. Cumulative analytical side drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0462	0.0525
CV lid	Type 304L stainless steel	0.0004	0.0004
CV closure nut	A-479 nitronic 60	0.0000	0.0005
Angle	Type 304 stainless steel	0.0816	0.0845
Drum	Type 304 stainless steel	0.2623	0.2814
Drum bottom	Type 304 stainless steel	0.2807	0.2827
Liner	Type 304 stainless steel	0.2005	0.2022
Lid	Type 304 stainless steel	0.6411	0.6413
Lid stiffener	Type 304 stainless steel	0.0217	0.0171
Drum studs	Type 304 stainless steel	0.1753	0.2364
Drum hex nut	Silicon bronze - C65100	0.0000	0.0018
Drum washer	300 series stainless steel	0.1034	0.0439
Top plug weldment	Type 304 stainless steel	0.1258	0.1286

Table 2.58. Diametrical damage comparison of Test Unit-3 with analytical predictions [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	19.25	19	19	19.06	19	19
Top rolling hoop	18.75	18.9	18.9	20.25	20.6	20.6
CG & top rolling hoop	19.25	19.4	19.4	19.75	19.9	19.8
CG rolling hoop	19.13	19.3	19.3	19.25	19.4	19.4
Bottom rolling hoop	19.13	19.3	19.3	19.75	20.4	20.4
Bottom false wire	18	18.6	18.6	19.38	19.4	19.4

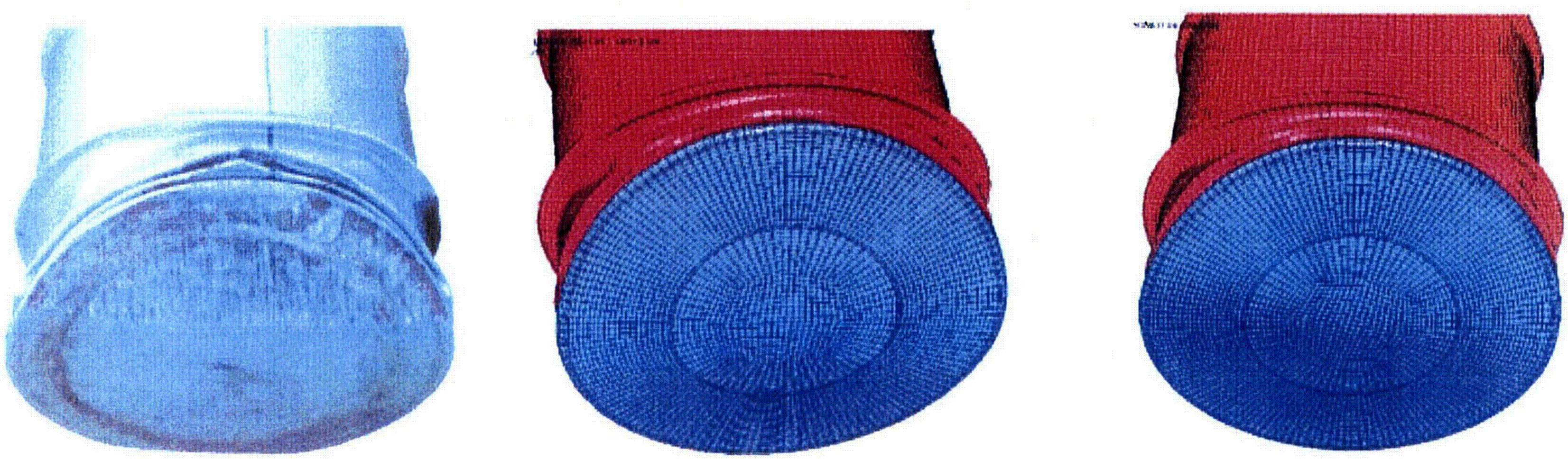


Fig. 2.28. Visual comparison of the cumulative bottom damage after the three drop tests (from left to right: Test Unit-3, analytical results with BoroBond, analytical results with Cat 277-4).

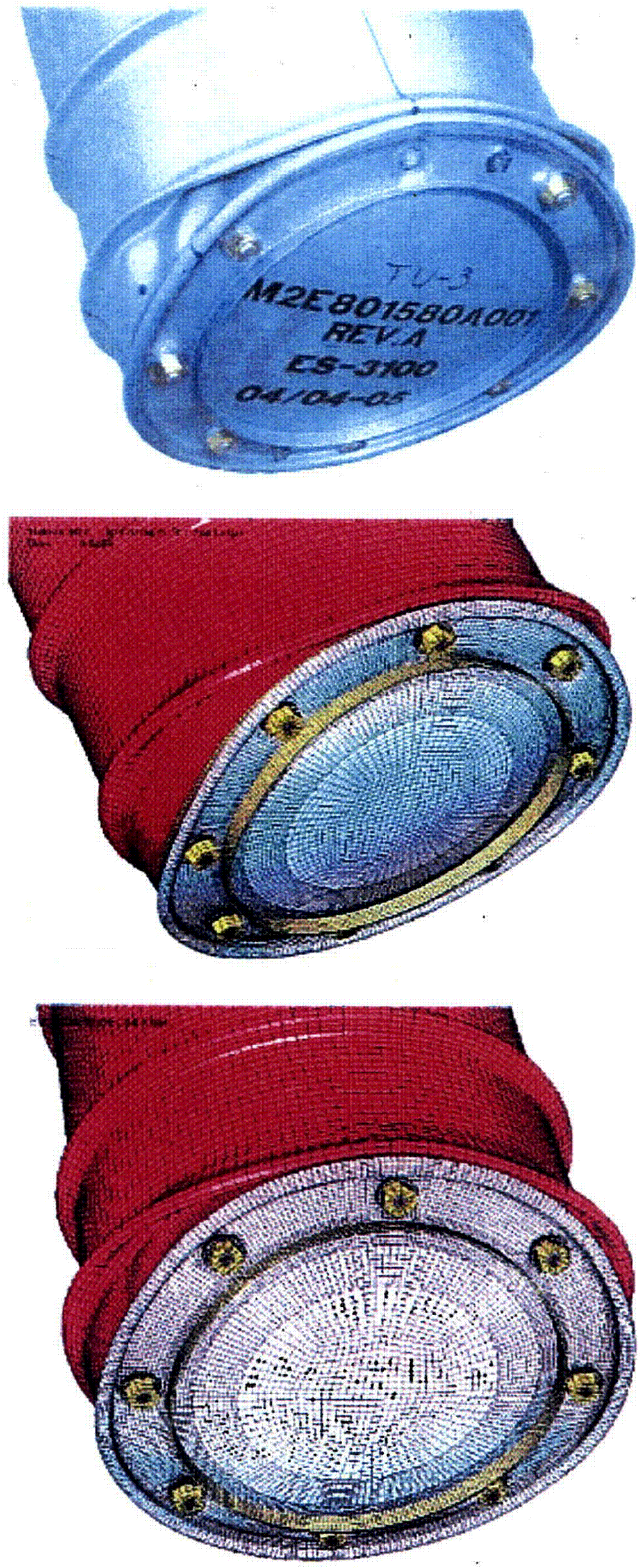


Fig. 2.29. Visual comparison of the cumulative lid damage after the three drop tests (from top to bottom: Test Unit-3, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.59. Cumulative analytical corner drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0364	0.0371
CV lid	Type 304L stainless steel	0.0024	0.0051
CV closure nut	A-479 nitronic 60	0.0000	0.0002
Angle	Type 304 stainless steel	0.0464	0.0462
Drum	Type 304 stainless steel	0.3787	0.3830
Drum bottom	Type 304 stainless steel	0.0731	0.0761
Liner	Type 304 stainless steel	0.5507	0.5254
Lid	Type 304 stainless steel	0.3579	0.3622
Lid stiffener	Type 304 stainless steel	0.0272	0.0272
Drum studs	Type 304 stainless steel	0.5578	0.5598
Drum hex nut	Silicon bronze - C65100	0.2258	0.2266
Drum washer	300 series stainless steel	0.1111	0.1528
Top plug weldment	Type 304 stainless steel	0.1170	0.1166

Table 2.60. Diametrical damage comparison of Test Unit-4 with analytical predictions [Diameter (in.)]

Axial measurement location	0 to 180°			90 to 270°		
	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4	Test results	Analytical results with BoroBond	Analytical results with Cat 277-4
Top false wire	19.25	19.3	19.3	19.38	19.3	19.3
Top rolling hoop	20.00	20.2	20.1	20.13	20.2	20.1
CG & top rolling hoop	20.00	20.2	20.2	20.06	20.2	20.2
CG rolling hoop	19.44	20.1	20.1	19.5	20.1	20.1
Bottom rolling hoop	19.94	20.5	20.5	20	20.5	20.5
Bottom false wire	19.25	19.4	19.4	19.25	19.4	19.4

Fig. 2.30. Visual comparison of the cumulative damage after the three drop tests (from left to right: Test Unit-4, analytical results with BoroBond, analytical results with Cat 277-4).

Table 2.61. Cumulative analytical top drop test maximum effective plastic strain results

Component	Component material	Effective plastic strain (in./in.)	
		Model with BoroBond	Model with Cat 277-4
CV body	Type 304L stainless steel	0.0053	0.0083
CV lid	Type 304L stainless steel	0.0034	0.0072
CV closure nut	A-479 nitronic 60	0.0000	0.0011
Angle	Type 304 stainless steel	0.0304	0.0308
Drum	Type 304 stainless steel	0.1258	0.1237
Drum bottom	Type 304 stainless steel	0.0312	0.0267
Liner	Type 304 stainless steel	0.3585	0.3812
Lid	Type 304 stainless steel	0.1415	0.1389
Lid stiffener	Type 304 stainless steel	0.0098	0.0100
Drum studs	Type 304 stainless steel	0.1541	0.1535
Drum hex nuts	Silicon bronze - C65100	0.0170	0.0173
Drum washer	300 series stainless steel	0.0510	0.0506
Top plug weldment	Type 304 stainless steel	0.0944	0.0960

Table 2.62. ES-3100 test package weights before and after 10 CFR 71.73(c)(4) HAC thermal testing

Test Unit	Pre-test[a] weight kg (lb)	Post-test[a] weight kg (lb)	Thermal test weight loss kg (lb)	BoroBond4 original weight[b] kg (lb)	Water weight in BoroBond4[c] kg (lb)	Water loss percent[d] (%)
1	202.3 (446)	202.3 (446)	0.0 (0)	20.7 (45.64)	4.91 (10.82)	0.00
2	202.8 (447)	202.8 (447)	0.0 (0)	20.5 (45.19)	4.86 (10.72)	0
3	203.7 (449)	203.2 (448)	0.45 (1)	20.5 (45.19)	4.87 (10.74)	9.31
4	201.8 (445)	201.4 (444)	0.45 (1)	20.4 (44.97)	4.84 (10.66)	9.38
5	157.4 (347)	156.9 (346)	0.45 (1)	20.6 (45.42)	4.89 (10.77)	9.29

[a] Data from the test report. (Appendix 2.10.7)
[b] Weight of BoroBond4 and water obtained from casting data. (ES-3100 Weldments)
[c] This weight is based on TGA measurements and calculation showing that the minimum water percent is 23.71%.
[d] All weight loss attributed to loss of water in BoroBond4.

could be postulated that the additional pressure differential (ambient on the exterior and a near vacuum inside) would help to further compress the O-rings during this test. However, since the containment vessel closure nut is screwed down, the additional pressure does not compress the O-ring more than a few ten thousands of an inch based on mismatch between the internal and external threaded joint. Only rotation of the closure nut will alter O-ring compression significantly. Pictures taken of all containment vessel tops following testing showed that the closure nut had rotated a maximum of 0.15 cm (0.060 in.) [Fig. 2.31] from its original radial position obtained during assembly (Fig. 2.32) except for Test Unit-4, which showed no rotation. Based on the pitch of the closure nut, this rotation translates into only 0.0009 cm (0.00035 in.) decompression of the O-rings. This compares to the original nominal compression of 0.064 cm (0.025 in.). According to the *Parker O-Ring Handbook*, the minimum squeeze for all seals, regardless of cross section should be about 0.018 cm (0.007 in.). Using the nominal compression of 0.064 cm (0.025 in.) and subtracting the decompression from rotation and the minimal pressure differential compression, there is ample O-ring compression. Therefore, the leak test in either direction for this containment vessel arrangement is valid. As required in 10 CFR 71.73(c)(5), the containment vessels were submerged under a 0.9-m (3-ft) head of water following the leakage tests, with no water in-leakage permitted. Following this immersion test, the containment vessels were opened. 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 162.7 ± 6.8 N·m (120 ± 5 ft-lb). The lowest break-loose torque value of 40.7 N·m (30 ft-lb) was recorded for Test Unit-4. Visual inspection following the testing indicated that neither the vessel bodies, the O-rings, the seal areas, nor the vessel lid assemblies were damaged during the tests. In Test Unit-5, the convenience cans had buckled from the pressure differential caused during the leak testing operation. However, the containment vessel wall showed little or no signs of impact. Therefore, based on the success of these six test units (including the containment vessel of Test Unit-6) and the analytical drop simulation effort, the structural integrity of the ES-3100 package, with the previously mentioned modifications, meets all the applicable requirements of 10 CFR 71.73 for transport of the proposed contents.

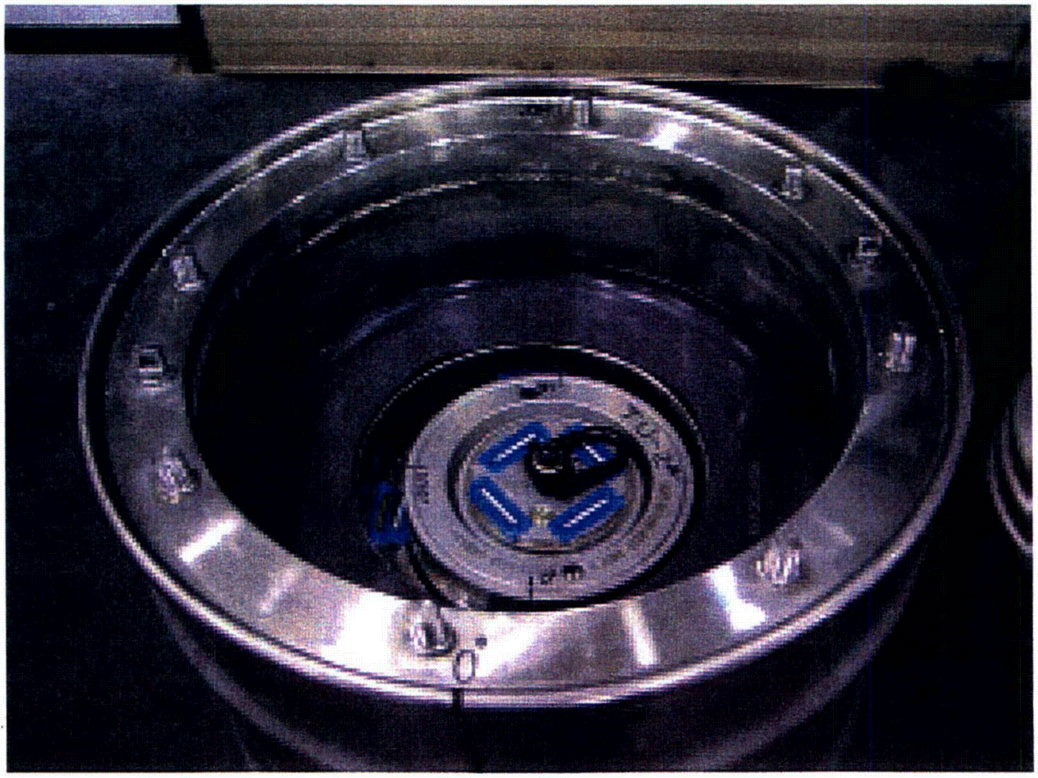


Fig. 2.31. Containment vessel markings at assembly (swivel hoist ring removed prior to testing).

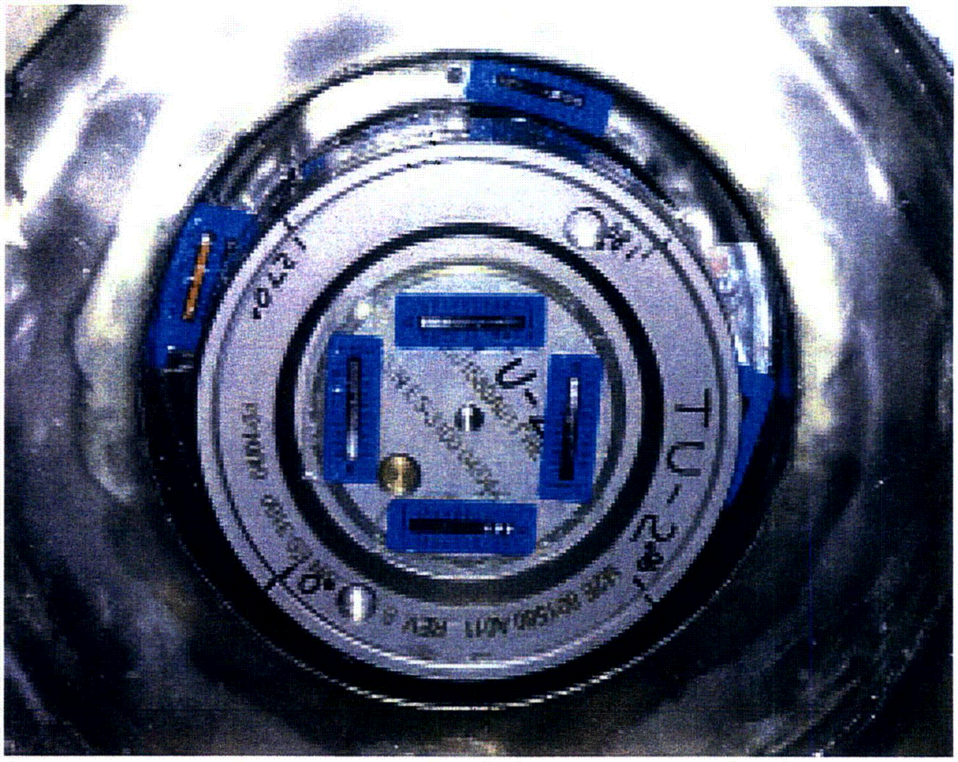


Fig. 2.32. Containment vessel marking after compliance testing.

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

The proposed contents are not shipped by air; therefore, this section is not applicable.

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

The expanded test conditions specified in 10 CFR 71.55(f)(1), (2), or (3) for fissile material package designs for air transportation was not conducted. The issue of subcriticality is addressed in Section 6 with content mass limits as addressed in Section 1 for air transport.

2.9a SPECIAL FORM

The package does not include any special form of radioactive material. Hence, the requirements of 10 CFR 71.75 and 71.77 are not applicable.

2.9b FUEL RODS

The contents do not utilize cladding for the containment of radioactive materials. Therefore, this requirement is not applicable.

2.10 APPENDICES

Appendix	Description
2.10.1	ES-3100 CONTAINMENT VESSEL ASME CODE EVALUATION (DAC-EA-900000-A006 and DAC-EA-900000-A007)
2.10.2	IMPACT ANALYSES OF ES-3100 DESIGN CONCEPTS USING BOROBOND AND CAT 277-4 NEUTRON ABSORBERS
2.10.3	KAOLITE PROPERTIES
2.10.4	CATALOG 277-4 PROPERTIES
2.10.5	BOROBOND4 PROPERTIES
2.10.6	RECOMMENDED RANDOM VIBRATION AND SHOCK TEST SPECIFICATIONS FOR CARGO TRANSPORTED ON SST AND SGT TRAILERS
2.10.7	TEST REPORT OF THE ES-3100 PACKAGE; VOL 1 - MAIN REPORT, ORNL/NTRC-013/V1; SEPT. 10, 2004
2.10.8	THE ES-3100 TEST REPORT; VOL. 3, APPENDIX K - TU-4 DATA SHEETS
2.10.9	PACKAGING MATERIALS OUTGASSING STUDY FINAL REPORT

APPENDIX 2.10.1

ES-3100 CONTAINMENT VESSEL ASME CODE EVALUATION (DAC-EA-900000-A006 and DAC-EA-900000-A007)

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 1 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

TABLE OF CONTENTS

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 2 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

OBJECTIVE

The design for the ES-3100 Containment Vessel is evaluated for compliance with ASME Code, Section III structural design rules using bounding loads taken from the U. S. Code of Federal Register and International Atomic Energy Agency Requirements.

EVALUATION INPUT (CRITERIA) AND SOURCE

REFERENCES USED

BWXT Y-12 drawings (Project: ES-3100 Shipping Package, all dated 10/29/03):

M2E801580A011, Rev. C, "Containment Vessel Assembly"

M2E801580A012, Rev. C, "Containment Vessel Body Assembly"

M2E801580A013, Rev. B, "Containment Vessel O-ring Details"

M2E801580A014, Rev. B, "Containment Vessel Lid Assembly"

M2E801580A015, Rev. C, "Containment Vessel Sealing Lid"

M2E801580A016, Rev. B, "Containment Vessel Closure Nut"

Texts

(B1.1) *Unified Inch Screw Threads*, ASME B1.1-1989, The American Society of Mechanical Engineers, 1989.

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

(CFR) *Packaging and Transportation of Radioactive Material*, 10CFR71, Code of Federal Regulations, the Nuclear Regulatory Commission, 2004.

(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.

(IAEA) *Regulations for the Safe Transport of Radioactive Material, Requirements*, 1996 Edition (Revised), No. TS-R-1 (ST-1, Revised), International Atomic Energy Agency, 2000.

(Parker) *Parker O-Ring Handbook*, 2001 Edition, Catalog ORD 5700A/US, Parker Seals, 2001.

(Roark) R. J. Roark and W. C. Young, *Formulas for Stress and Strain*, 5th Ed., McGraw-Hill Book Company, 1975, p. 363.

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

ASSUMPTIONS MADE

Calculations are based on geometry and specifications from referenced drawings.

Results are rounded to significant figures although more digits may be retained in intermediate calculations.

IDENTIFICATION OF COMPUTER CALCULATION

Computer Type: Dell PC x86 Family processor Family 6 Model 8 Stepping 1 using the Microsoft Windows 2000 operating system level 5.00.2195 with Service Pack 4.

Computer Program Name, Revision, Verification, Applicability: Programs used were Algor (R) Linear Static Stress Version 12.26-WIN 28-OCT-2002, ALG.DLL VERSION:13180000 and FEMPRO Version 13.26-WIN 22-NOV-2002. Verification was by running example programs with known solutions on the same computer used for final calculations. The expected results were produced exactly. Hand calculations are used here to confirm results. The program is applicable to linear elastic solutions for bodies of revolution as needed here.

METHODS TO BE USED

The Finite Element Method is used to determine the response of the CV components to internal pressure and gasket seating loads. External pressure resistance of the cylindrical shell is evaluated following Code rules. The finite element results also serve to demonstrate the external pressure resistance of the lid and bottom of the CV. Buttress threads used to restrain the lid are evaluated by a method derived from an accepted way of determining the strength of standard threads.

ANALYSES AND/OR CALCULATIONS

DESIGN CONDITIONS

Internal Pressure: 101.5 psig at 300 F. per IAEA.

External Pressure: 21.7 psig at 300 F. per 10CFR71.73.

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 4 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

ALLOWABLE STRESS INTENSITIES

From Section II.

PART	SPECIFICATION	ALLOWABLESTRESS INTENSITY, PSI
Containment vessel	ASME SA-182, Type F304L forging or bar (<5 in. thick)	12,800 @ 300 F.*
Containment lid	ASME SA-479, 304 bar	12,800 @ 300 F.*
Closure nut	ASME SA-479, UNS-S21800 bar	22,100 @ 300 F.

* The lower of two allowable values was chosen to limit deflection of the flange.

NB-3133 COMPONENTS UNDER EXTERNAL PRESSURE

The design internal pressure is higher than the external pressure across the bottom of the vessel and the lid. Since stability or buckling was not an issue, these flat heads were evaluated for resistance to internal pressure only. They can resist the external pressure by linearity.

NB-3133.3 Cylindrical Shells and Tubular Products

Data: Outside diameter of cylindrical shell, D_o = 5.04" + 2(0.100") = 5.24"

Shell thickness, T = 0.100"

Total length, L = 32.40" – (0.25")/2 – 1.10" = 31.18"

$D_o/T = 52.4$

$L/D_o = 5.95$

From ASME Section II, Fig. G, A = 0.00053

From ASME Section II, Fig. HA-3, conservatively using the 400 F. curve, B(400 F.) = 4900.

The maximum acceptable external pressure in this case is $P_a = 4B/3(D_o/T)$ = 125 psig.

This allowable value exceeds the design external pressure and the shell is acceptable.

NB-3133.6 Cylinders Under Axial Compression

Data: Inside radius, R = 5.04"/2 = 2.52"

$A = 0.125/(R/T) = 0.0050$

From ASME Section II, Fig. HA-3, conservatively using the 400 F. curve, B(400 F.) = 7100.

This is the maximum acceptable compressive stress limited by axial buckling. The maximum external pressure applied to the axial cross section of the cylinder at 400 F. can be derived using nominal values from:

$$7100\,psi = \frac{p_e \frac{\pi}{4}(5.24\,in.)^2}{\frac{\pi}{4}\left[(5.24\,in.)^2 - (5.04\,in.)^2\right]}$$

p_e = 532 psi. This is less than the design external pressure and the shell is still acceptable.

NB-3200 DESIGN BY ANALYSIS

Individual axisymmetric finite element models were constructed of the CV body, the lid, and the closure nut and identified es5100, es3100lid, and es3100nut, respectively. Two loading conditions were applied to each model per Section III requirements: internal pressure and gasket seating. Load Case 1 is internal pressure including gasket load and Load Case 2 is gasket load alone.

The material properties at 300 F. obtained from Section II are as follows:

MATERIAL	MODULUS OF ELASTICITY	POISSON'S RATIO*
304 or 304L stainless steel	27,000,000 psi	0.3
UNS-S21800 stainless steel	27,000,000 psi**	0.3

* Typical values. Stress distributions are not sensitive to Poisson's ratios near 0.3 .

** Not in Tables. Based on principal constituents same as 304 stainless (18% Cr, 8% Ni).

<u>Gasket load</u>

Two concentric O-rings are specified to provide a redundant and testable seal. Per normal ASME practice, the O-ring grooves were not included in the finite element model. Elements reasonably close to the actual O-ring locations were chosen and elements representing the O-rings were added to the model of the CV. The gasket force was applied by displacing the top surface by 0.139 in. – 0.114 in. = 0.025 in. This way a reduction in gasket load will be caused by deformation of the CV from application of pressure.

Each O-ring has a 0.139 inch cross section diameter and is specified to have a 70 +/- 5 Shore A durometer reading. The O-ring manufacturer's catalog (Parker, P. A4-8) gives ranges of distributed force required to compress O-rings. The O-ring grooves cut into the flange surface are specified to be 0.114 inch deep. The lid is expected to be pressed down so contact is metal-to-metal. Then the O-rings will be compressed

$$\frac{0.025\,in.}{0.139\,in.} \times 100\,\% = 18.0\,\%$$

This is equivalent to a strain of 0.18 in./in.

Attachment A shows the effective distributed compression force for different amounts of compression based on values of distributed force averaged between high and low values for the highest allowed durometer reading, 75. The distributed force for 18% compression was about 20 lb/in. The stress-strain relationship for a thin annular shell t thick of average radius r loaded axially by the force F=20 lb/in(2 r) and an elastic modulus E is approximately

$$\frac{20\,lb/in(2\pi r)}{2\pi r t} = E\varepsilon = E(0.18\,in/in). \text{ So}$$

$$E = \frac{20\,lb/in}{0.18t}.$$

For the outer O-ring, the thickness is 3.04584 in. – 2.96172 in. and E_o = 1321 psi. For the inner O-ring, the thickness is 2.817 in. – 2.718 in. and E_i = 1122 psi.

These moduli were applied to the respective O-ring elements in the CV model.

Pressure was applied over the inner surface of the CV model up to the outer edge of the inner O-ring groove per Code rules. Two nodal forces had to be applied at the inner corner of the flange area since the program could not apply pressure to two faces of one element. The pressure and gasket seating forces were resisted by stiff elastic boundary elements canted 7 degrees out from the axis of symmetry to simulate the effect of the 7 degree surface on the threads to meet Code rules to consider radial forces and resulting hoop stress at the threads.

Results from the O-ring elements and the boundary element restraint are collected in Attachment B. The local 2-axes of the O-ring elements are parallel to the CV axis of symmetry, the global Z-axis. The values from load case 2 are -237.1 psi for the first set of elements representing the outer O-ring and -201.3 psi for the inner O-ring. These stresses were achieved by applying a displacement of 0.025 inches. The equivalent distributed loads in the O-ring elements are -237.1 psi (3.04584 in. – 2.96172 in.) = -19.94 lb/in. and -201.3 psi (2.817 in. – 2.718 in.) = -19.93 lb/in. which are within 1% of the target, 20 lb/in.

The gasket reaction forces and internal pressure were applied to a model of the lid. The nodal forces are shown in Attachment C. The lid was restrained by a portion of the surface under the nut. The contact area was moved radially inward until there was no tension developed during Load Case 1. The dimensions of the contact area may not be exact but the Code requirement to maintain equilibrium of forces and moments is met. One of the contact nodes for Load Case 2 was in tension but equilibrium of force and moment were still maintained by the force distribution applied to the model of the nut. Also Load Case 2 produces such low stresses that optimizing the model for it is unnecessary.

The interface forces were applied to a model of the nut. The force magnitude and moment of the distributed forces was maintained using small added nodal forces as shown in Attachment D.

The distribution of stress intensity is shown on Figs. 1 – 10. Stress intensities are very low relative to the basic allowable stress for the material. Code compliance is trivial since the Code tests subdivide the computer results but the sum is less than the allowable for any of the subsets. By the numbers.

<u>NB-3221.1 General Primary Membrane Stress Intensity</u>

General primary membrane stress intensity is limited to the basic allowable stress intensity at temperature. That is 12,800 psi in the CV. The general primary membrane stress intensity is based on stresses averaged across the thickness of a section. The highest calculated stress intensities (called 2 times Tresca Stress by the program) were 7436 psi for Load Case 1 and 1203 psi for Load Case 2. Average stress is always less than peak stress so the CV is acceptable.

Fig. 4 is a close look at the cylindrical section. The stress intensity away from thickened sections appears to be less than 3000 psi. As a check the average elastic stresses in the middle of the cylindrical side of the vessel are easily calculated from equilibrium. Section III of the ASME Code provides values in Nonmandatory Appendix A. The tolerance on critical dimensions is ±0.01 in. and is taken into consideration to calculate maximum values of stress intensity.

A-2221 General Primary Membrane Stress Intensity

$$S = (pR/t) + (p/2) = 101.5\,psig\left(\frac{5.04\,in. + 0.01\,in.}{2(0.10\,in. - 0.01\,in.)}\right) + \frac{101.5\,psig}{2} = 2898\,psi.$$

A-2222 Maximum Value of Primary Plus Secondary Stress Intensity

$$S = 2pY^2/(Y^2-1) = \frac{2(101.5\,psig)\left(\dfrac{5.04\,in. + 0.01\,in.}{5.04\,in. + 0.01\,in. - 2(0.10\,in. - 0.01\,in.)}\right)^2}{\left(\dfrac{5.04\,in. + 0.01\,in.}{5.04\,in. + 0.01\,in. - 2(0.10\,in. - 0.01\,in.)}\right)^2 - 1} = 2899\,psi.$$

This confirms the computer solution for the cylindrical section.

There is a small radial membrane stress in the CV bottom but there is no need to calculate it since the sum of all order stresses is less than the allowable for the membrane stress.

The highest calculated stress intensity in the lid was 2398 psi for Load Case 1 and 872 psi for Load Case 2. The general primary membrane radial stress in the lid is zero from equilibrium so the highest average membrane stress is p/2 = 200 psi/2 = 100 psi. The allowable stress intensity is also 12,800 psi so the lid is acceptable.

<u>NB-3221.2 Local Membrane Stress Intensity</u>

Local membrane stress intensity is the average stress across the thickness of a cross section at the junction between the side and bottom of the CV. The allowable value of this stress component is 1.5 times the basic allowable stress. Figs. 4 and 5 show that the peak values of stress at this junction are below the basic allowable so the average must also be below the allowable and the CV is acceptable.

<u>NB-3221.3 Primary Membrane plus Primary Bending Stress Intensity</u>

Primary membrane plus primary bending stress intensity in the CV bottom and the lid.

Fig. 3 shows the stress intensity at the center of the CV bottom. The distribution is primarily due to bending and the peak value is less than 1.5 times the basic allowable stress intensity.

The stress in the bottom cover is complicated by attachment to the side but bending stress at the center can be checked by bounding stress by assuming both simple support and fixed support around the outside edge. From the Code Appendix:

A-5212 Radial bending stress at center (r = 0) and outside surface (x = t/2)

$$\sigma_r = p\frac{3(x)}{4t^3}\left[(3+\nu)(R^2-r^2)\right] = 101.5\,psig\frac{3(t/2)}{4t^3}\left[(3+0.3)\left(\frac{5.04\,in.}{2}\right)^2\right]$$

$$= 101.5\,psig\frac{3}{8(0.25\,in.)^2}\left[3.3(2.52\,in.)^2\right] = 12{,}762\,psi.$$

This equation is based on a simply supported outer edge. For a fixed edge, the stress at the same point using Roark (Table 24, Case 10b) is:

$$\sigma_r = p\frac{6}{16(0.25\,in.)^2}\left[(1+\nu)R^2\right] = 101.5\,psig\frac{3}{8(0.25\,in.)^2}\left[1.3(2.52\,in.)^2\right] = 5{,}028\,psi.$$

From Fig. 3 it is seen that the peak stress intensity at the center of the CV bottom is about 7,000 psi. This value is between the bending stresses for the simply supported and fixed edge cases as expected.

The pattern of stress intensity in the lid is also primarily bending of the relatively thin outboard edge with bearing under the restraining nut and some intensification at a fillet. The bending stress appears to be less than 300 psi which is far below the allowable.

NB-3222.3 Expansion Stress Intensity

Expansion stress intensity is undefined but can be bounded. The largest temperature range possible for the CV is between -40 F. which is the minimum temperature specified in 10CFR71 and 300 F. defined here. Suppose a tendril maintains a temperature of -14 F. while the surrounding material is heated to 300 F. The result is a 340 F. temperature difference across a sharp boundary – an infinite gradient. The stress in the tendril would be $\sigma = E\alpha_{(-40)-300}\,340^\circ$. E is the cold modulus of elasticity – 28,800,000 psi by interpolation from Table TM-1 in Section II. The temperature at the midpoint of the range is 170 F. and the instantaneous αat that temperature is 9.1×10^{-6} in/in/° F. from Table TE-1 in Section II. The bounding expansion stress is 89,000 psi. This is a fictitious elastic stress per the Code. Add to this the highest stress from the CV and lid models multiplied by an intensification factor of 2 since the finite element program may extrapolate to the surface too simplistically. That is 89,000 psi + 2 (7436 psi) = 100,000 psi. The alternating stress is half this value or 50,000 psi. The allowable number of cycles for this stress per Fig. I-9.2.1 in Code Mandatory Appendix I is 30,000. The vessel should acceptable for a few hundred years although a severe transportation accident should be counted as two cycles, one for impact and one for fire.

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 mode inward and do not increase the gap. In any case the calculated displacements are smaller than the thread tolerances. So, limited to thread properties

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

$$\begin{aligned} t_e &= \left(0.89064\,p - 0.14532\,p - gap\right)\left(\tan(7^\circ) + \tan(45^\circ)\right) \\ &= \left((0.89064 - 0.14532)(0.125\,in.) - 0.0134\,in.\right)(1.1228) \\ &= 0.08956\,in. \end{aligned}$$

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

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

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

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 ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 11 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

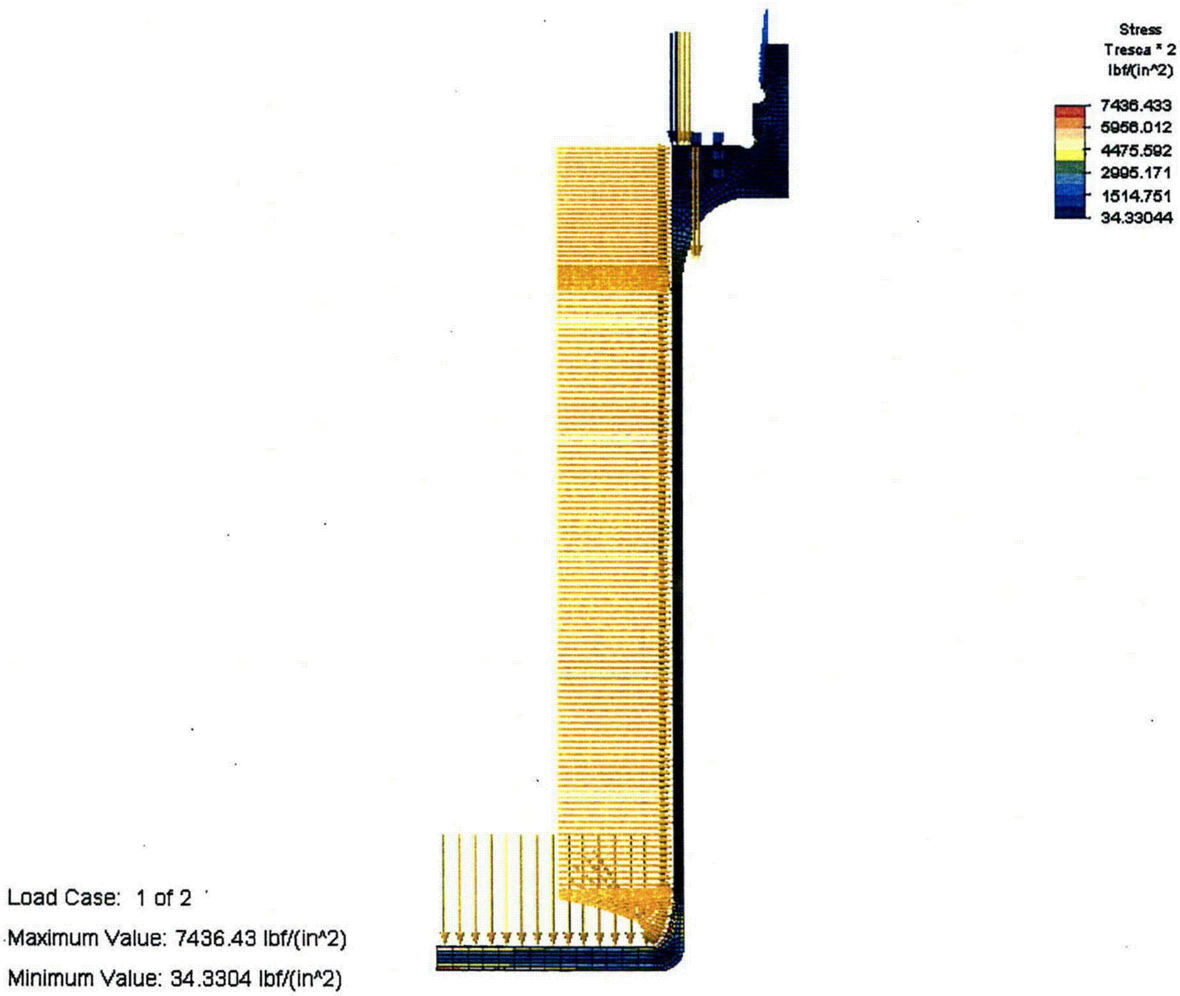


Fig. 1 – Stress Intensity in Containment Vessel due to Load Case 1

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 12 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

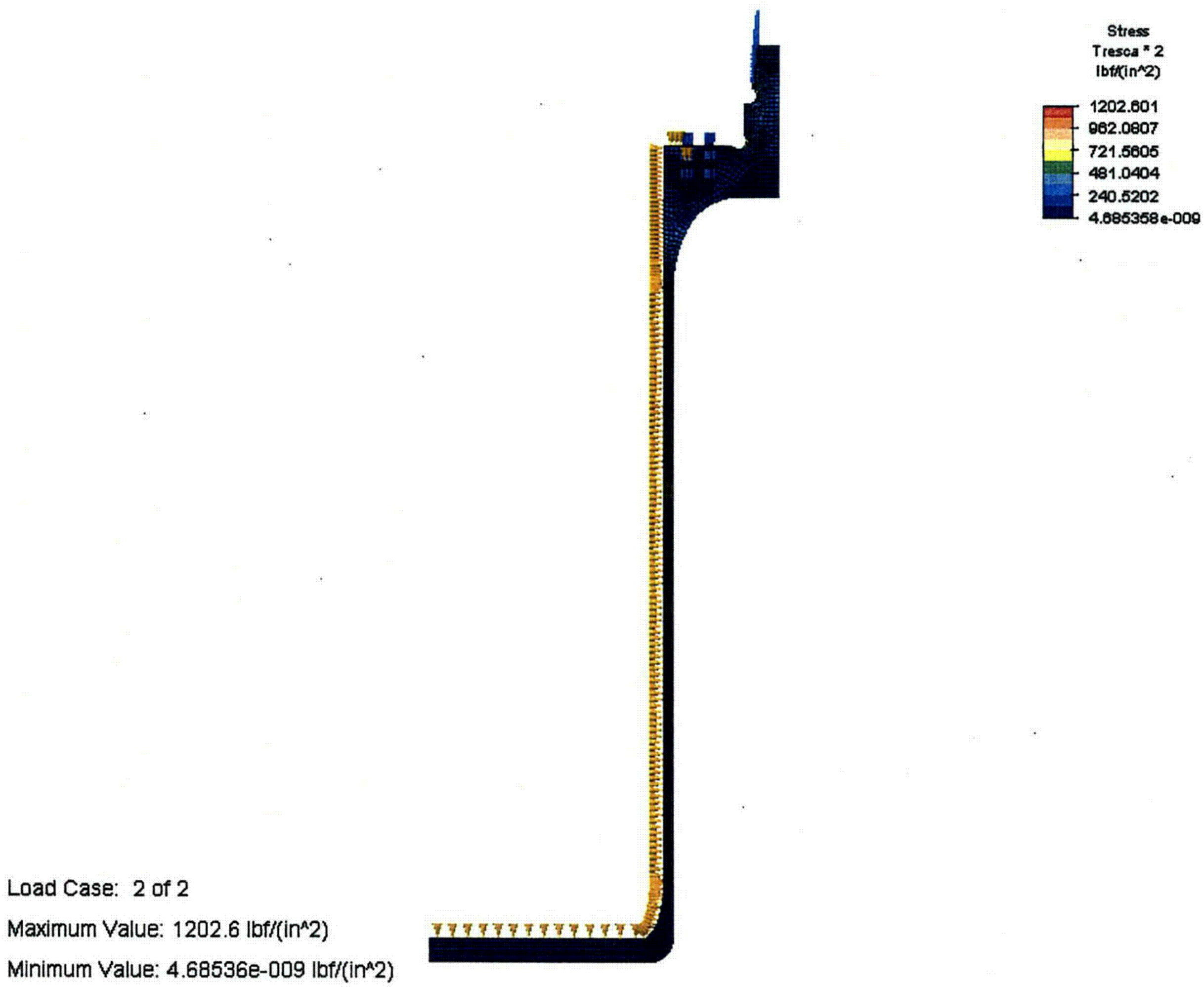
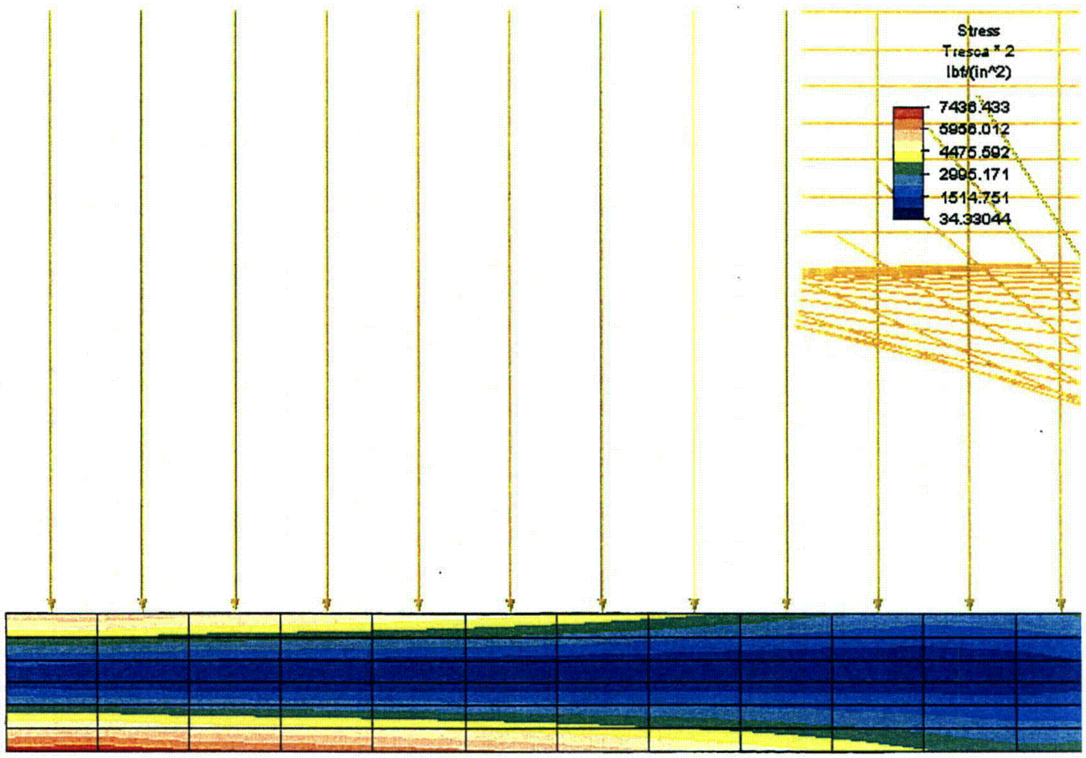


Fig. 2 – Stress Intensity in Containment Vessel due to Load Case 2

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 13 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee



Load Case: 1 of 2

Maximum Value: 7436.43 lbf/(in^2)

Minimum Value: 34.3304 lbf/(in^2)

Fig. 3 – Stress Intensity in the Bottom of the Containment Vessel due to Load Case 1

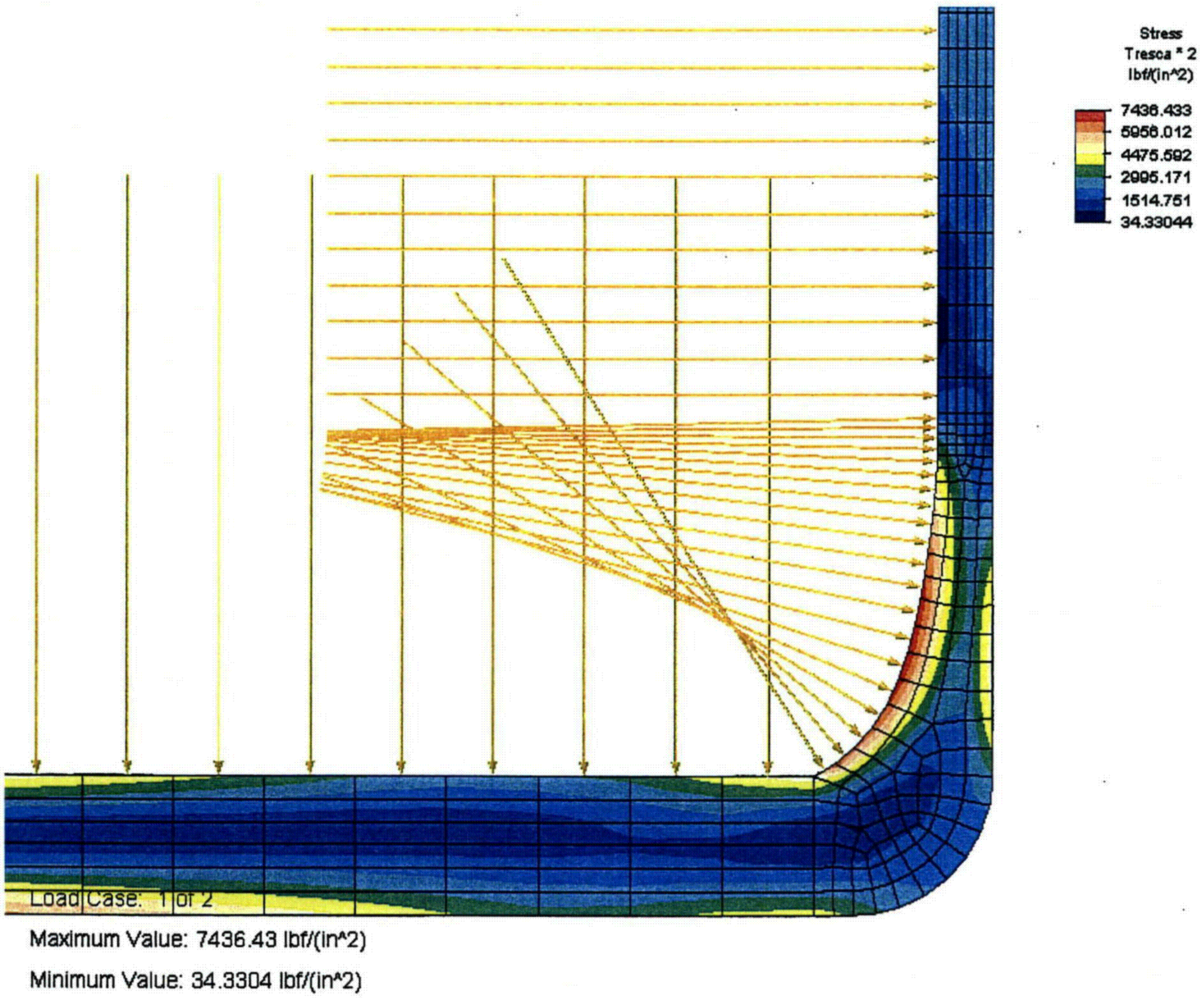


Fig. 4 – Stress Intensity at Junction of Bottom and Side of Containment Vessel due to Load Case 1

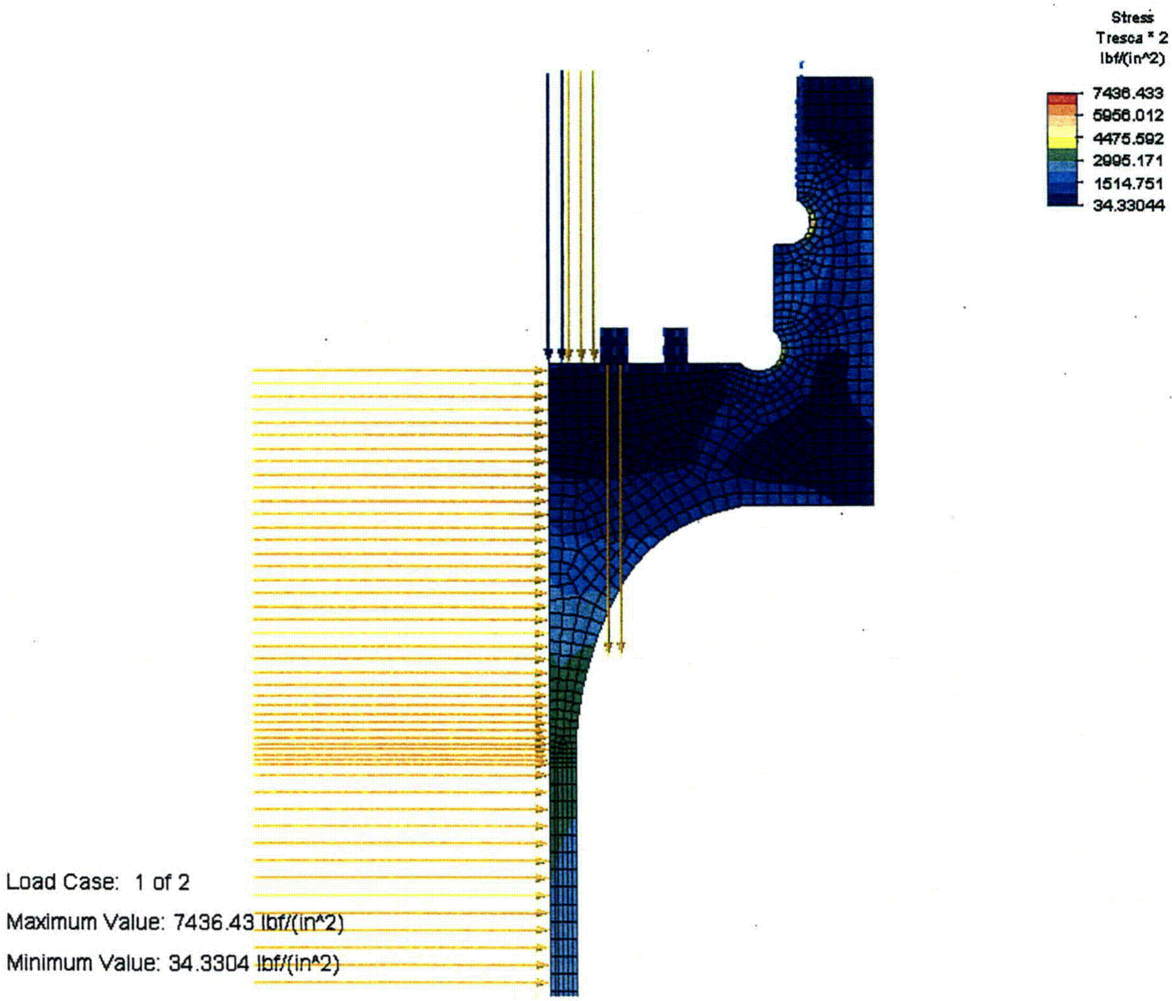


Fig. 5 – Stress Intensity in Flange Region of Containment Vessel due to Load Case 1

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 16 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

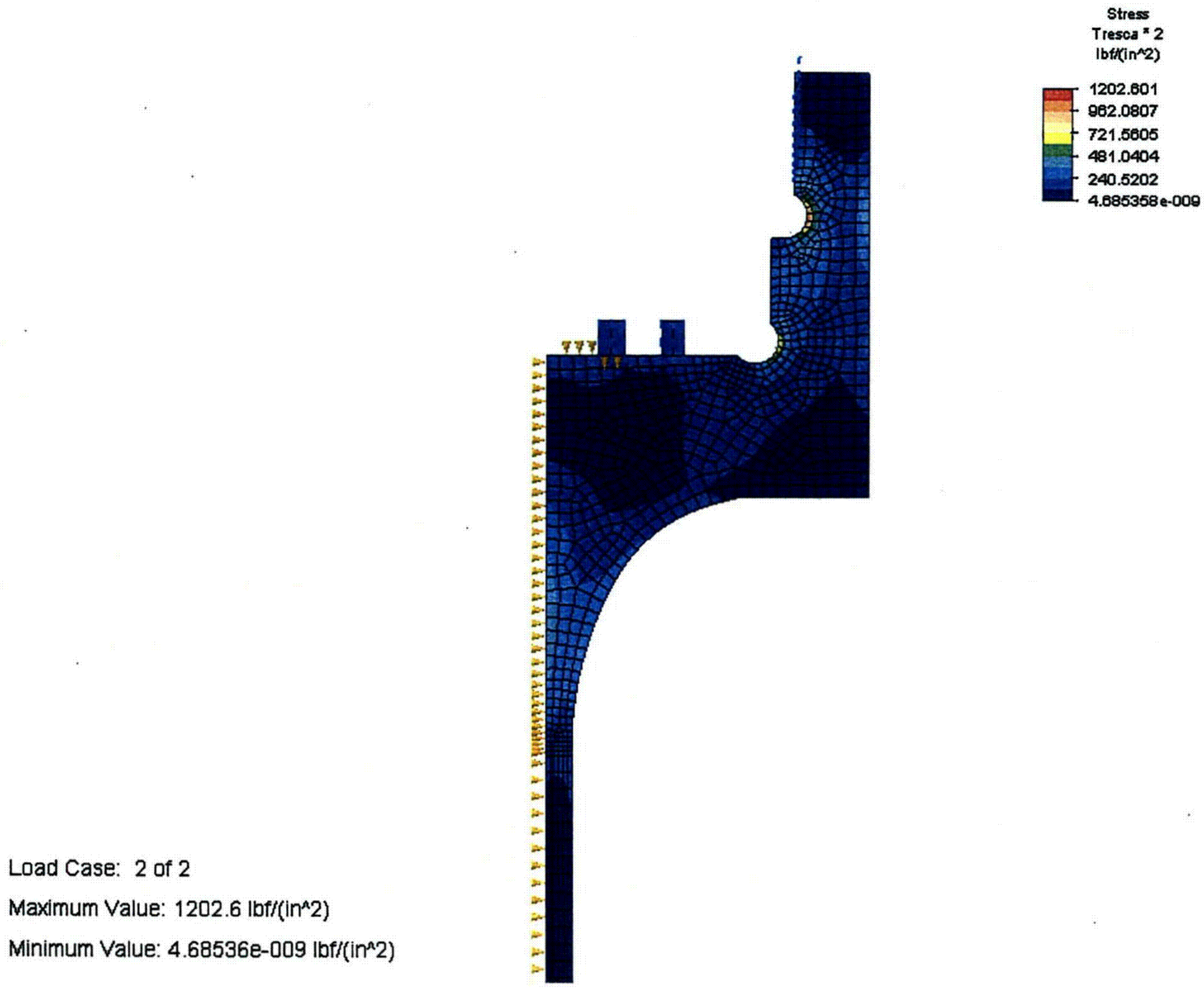
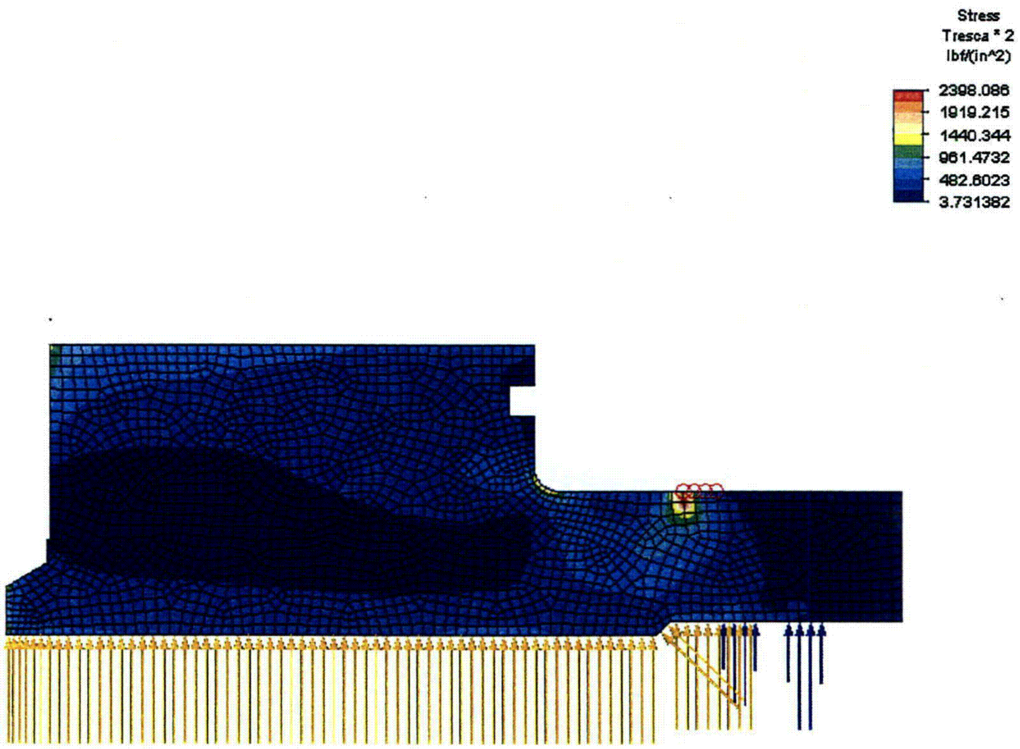


Fig. 6 – Stress Intensity in Flange Region of Containment Vessel due to Load Case 2

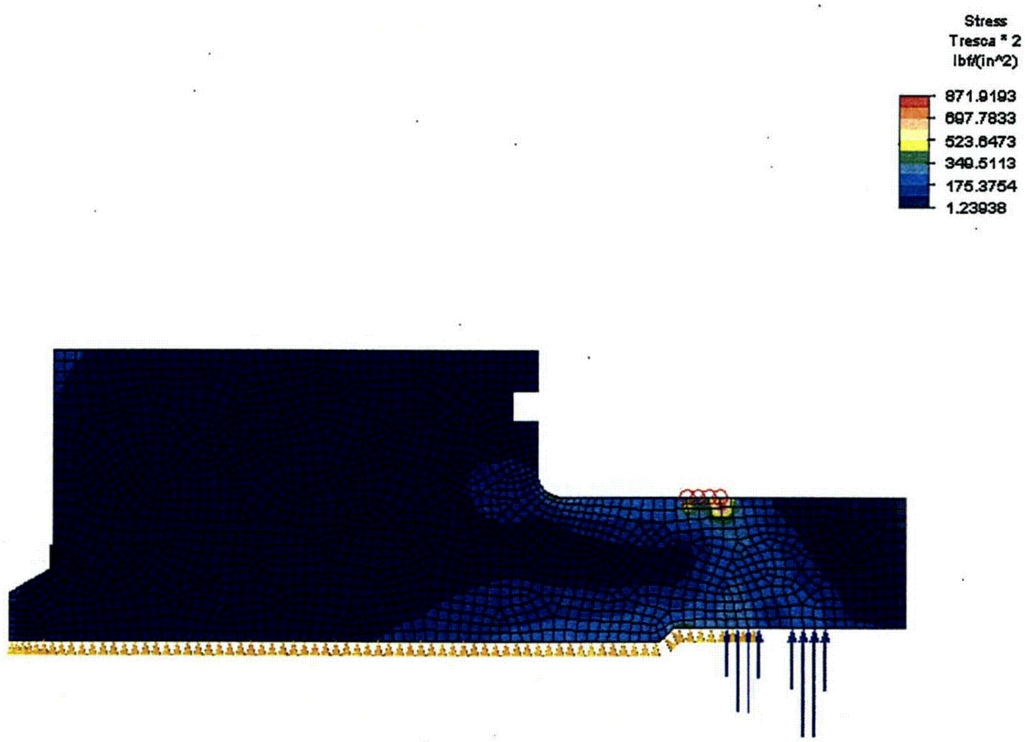


Load Case: 1 of 2

Maximum Value: 2398.09 lbf/(in^2)

Minimum Value: 3.73138 lbf/(in^2)

Fig. 7 – Stress Intensity in CV Lid due to Load Case 1



Load Case: 2 of 2

Maximum Value: 871.919 lbf/(in^2)

Minimum Value: 1.23938 lbf/(in^2)

Fig. 8 – Stress Intensity in CV Lid due to Load Case 2

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel	DATE 14 December 2006	SHEET 19 of 26

DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

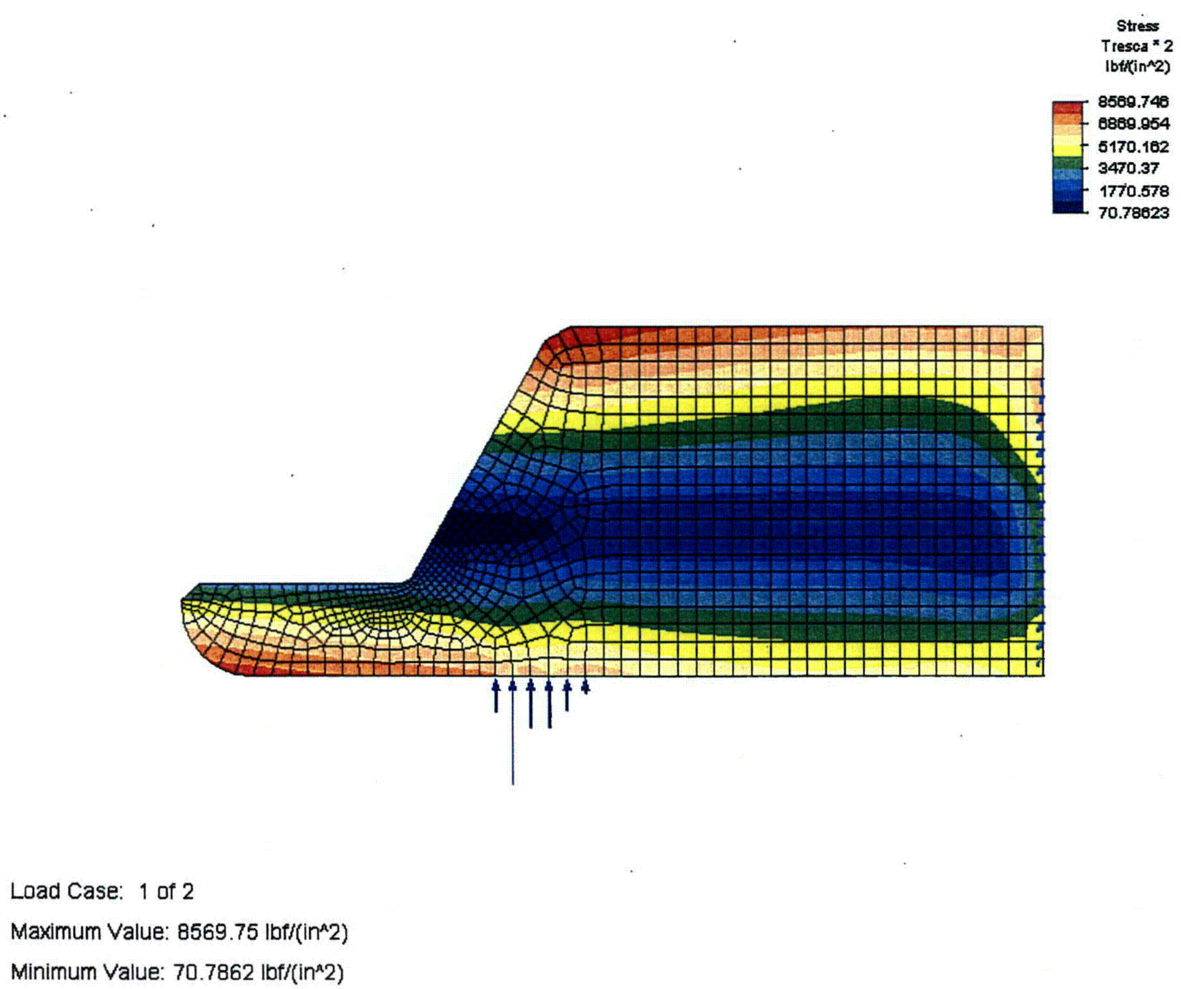
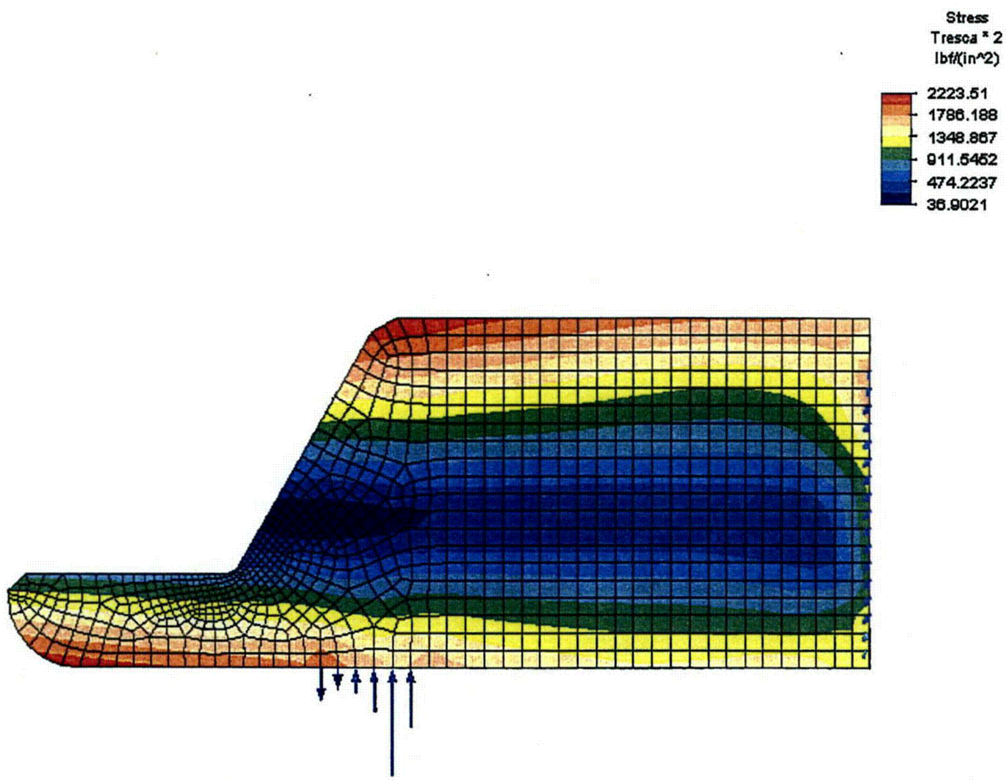


Fig. 9 – Stress Intensity in Nut due to Load Case 1



Load Case: 2 of 2

Maximum Value: 2223.51 lbf/(in^2)

Minimum Value: 36.9021 lbf/(in^2)

Fig. 10 – Stress Intensity in Nut due to Load Case 2

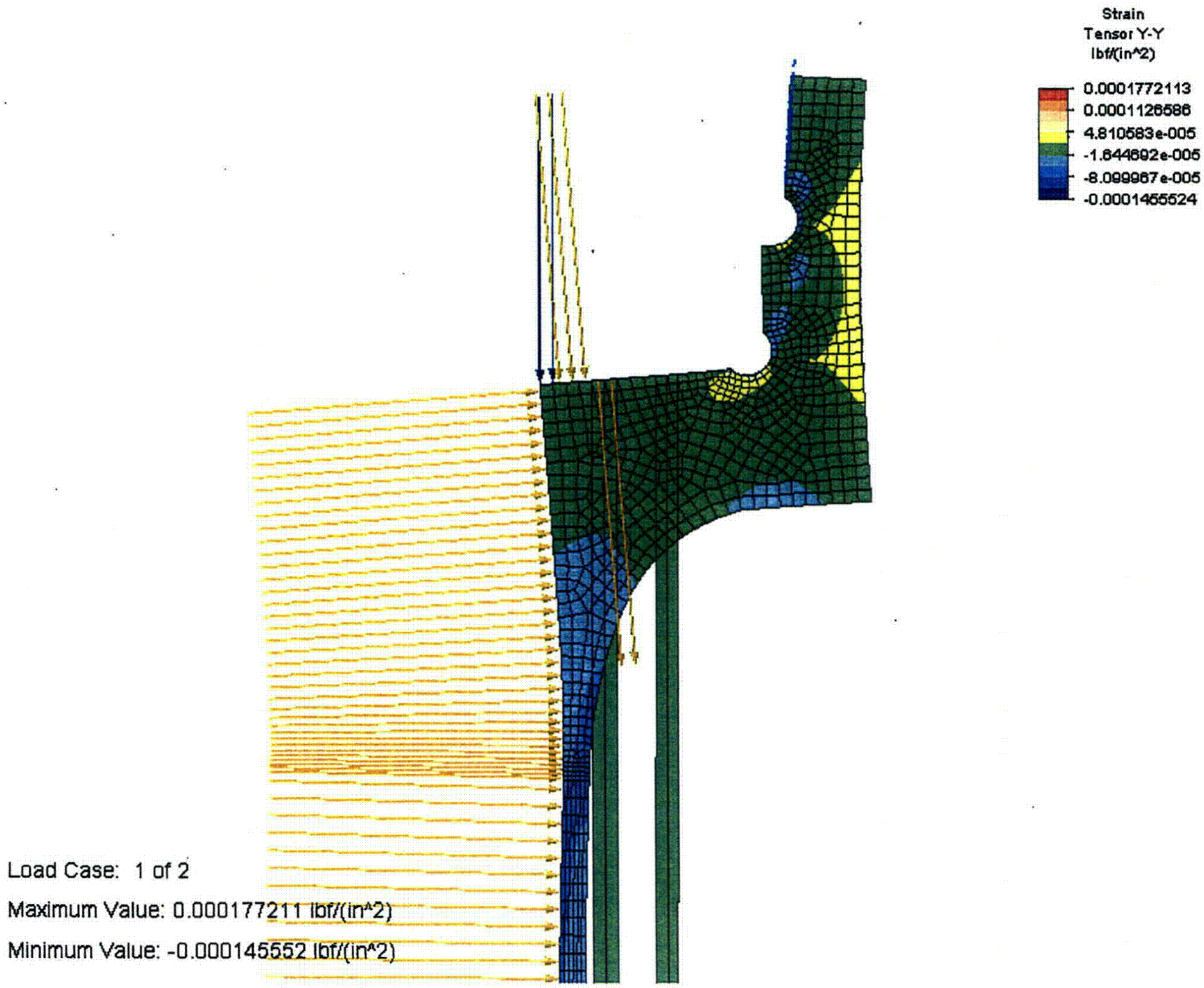


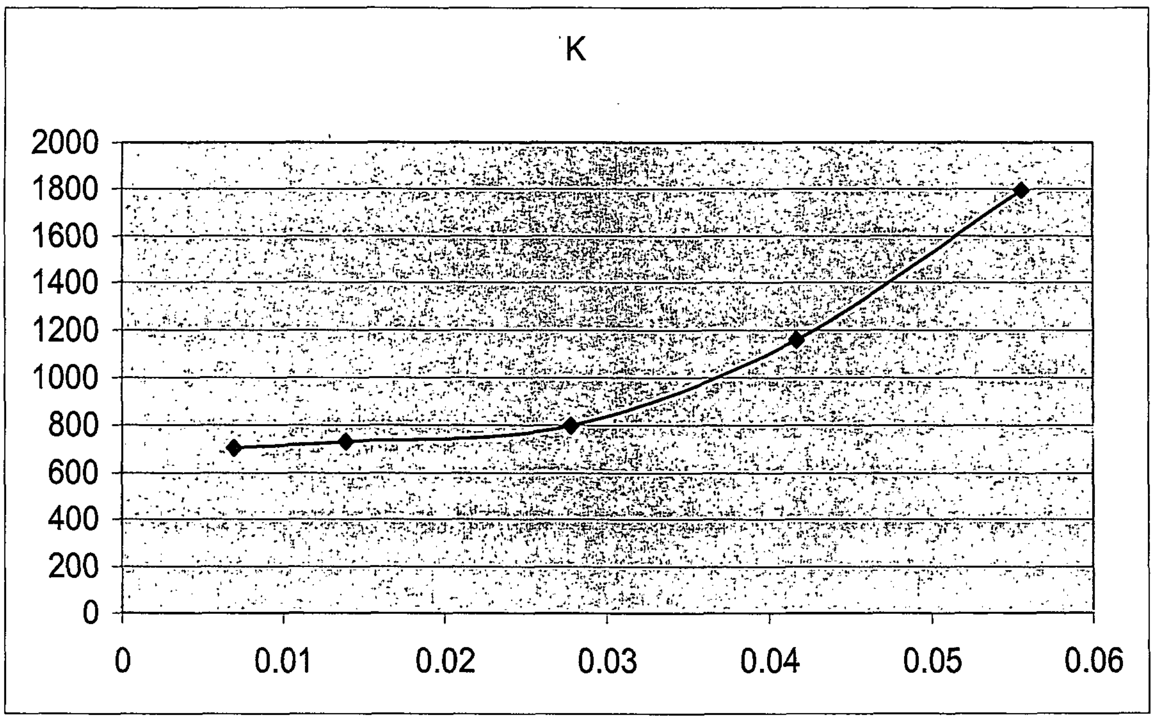
Fig. 11 – Radial Strain in the Flange Region of the Containment Vessel due to Load Case 1 (Distortion is Exaggerated)

ATTACHMENT A – O-RING SPRING CONSTANT

Compression of 0.139 in. dia. O-ring (Parker Seals, "O-Ring Handbook," ORD-5700A/US, 2001) [a]

Diameter = 0.139 D = 70 D = 80

% compression		Force Min	Max			Ave	Del	K
5	0.00695	0.93	6.1	2.5	10	4.8825	0.00695	702.518
10	0.0139	2	14	4.5	20	10.125	0.0139	728.4173
20	0.0278	4.5	30	9	45	22.125	0.0278	795.8633
30	0.0417	11	72	20	90	48.25	0.0417	1157.074
40	0.0556	19	160	40	180	99.75	0.0556	1794.065



a. Page 2-15 in the O-ring Handbook.

GENERAL DESIGN AND COMPUTATION SHEET

JOB ASME Code Subsection NB Stress Analysis of ES-3100 Containment Vessel		DATE 14 December 2006	SHEET 23 of 26
DAC NO. DAC-EA-900000-A006	REVISION NO. 2	COMPUTED C. R. Hammond	CHECKED BY R. M. Jessee

ATTACHMENT B –RESULTS FOR O-RING ELEMENTS FROM FINITE ELEMENT ANALYSIS OF CONTAINMENT VESSEL

**** Nodal stresses for 2-D elasticity elements:

El. #	LC	ND	Sigma-11	Sigma-22	Sigma-33	Tau-12	Sigma-Max	Sigma-Min	Sigma-Int
1	1	I	7.151E-03	-2.347E+02	-3.629E-02	1.115E-02	7.152E-03	-2.347E+02	-3.629E-02
1	1	J	6.460E-03	-2.348E+02	-3.564E-02	1.099E-02	6.460E-03	-2.348E+02	-3.564E-02
1	1	K	7.565E-04	-2.348E+02	-4.589E-02	9.078E-03	7.568E-04	-2.348E+02	-4.589E-02
1	1	L	1.448E-03	-2.347E+02	-4.662E-02	9.233E-03	1.448E-03	-2.347E+02	-4.662E-02
1	2	I	-3.586E-03	-2.371E+02	-6.498E-03	8.397E-03	-3.586E-03	-2.371E+02	-6.498E-03
1	2	J	-3.713E-03	-2.371E+02	-6.454E-03	8.271E-03	-3.713E-03	-2.371E+02	-6.454E-03
1	2	K	5.712E-03	-2.371E+02	-7.804E-03	7.936E-03	5.712E-03	-2.371E+02	-7.804E-03
1	2	L	5.839E-03	-2.371E+02	-8.014E-03	8.062E-03	5.839E-03	-2.371E+02	-8.014E-03
2	1	I	8.755E-03	-2.348E+02	-3.608E-02	-8.886E-03	8.756E-03	-2.348E+02	-3.608E-02
2	1	J	8.182E-03	-2.350E+02	-3.552E-02	-8.763E-03	8.183E-03	-2.350E+02	-3.552E-02
2	1	K	-7.855E-05	-2.350E+02	-4.575E-02	-1.064E-02	-7.807E-05	-2.350E+02	-4.575E-02
2	1	L	4.944E-04	-2.348E+02	-4.633E-02	-1.077E-02	4.949E-04	-2.348E+02	-4.633E-02
2	2	I	-3.637E-03	-2.371E+02	-6.900E-03	-9.129E-03	-3.636E-03	-2.371E+02	-6.900E-03
2	2	J	-3.745E-03	-2.371E+02	-6.860E-03	-9.012E-03	-3.745E-03	-2.371E+02	-6.860E-03
2	2	K	5.687E-03	-2.371E+02	-8.074E-03	-9.358E-03	5.687E-03	-2.371E+02	-8.074E-03
2	2	L	5.795E-03	-2.371E+02	-8.250E-03	-9.475E-03	5.796E-03	-2.371E+02	-8.250E-03

**** 2-D Elasticity elements:

```
Number of elements       =    2
Number of materials      =    5
Maximum temperature pts  =    1
Analysis code            =    0
  0 : axisymmetric
  1 : plane strain
  2 : plane stress
Incompatible modes        =    0
  0 : included
  1 : not included
```

**** Nodal stresses for 2-D elasticity elements:

El. #	LC	ND	Sigma-11	Sigma-22	Sigma-33	Tau-12	Sigma-Max	Sigma-Min	Sigma-Int
1	1	I	1.838E-03	-1.987E+02	-3.397E-02	7.582E-03	1.838E-03	-1.987E+02	-3.397E-02
1	1	J	1.110E-03	-1.988E+02	-3.334E-02	7.464E-03	1.111E-03	-1.988E+02	-3.334E-02

1	1	K	1.855E-03	-1.988E+02	-4.282E-02	5.515E-03	1.856E-03	-1.988E+02	-4.282E-02
1	1	L	2.583E-03	-1.987E+02	-4.364E-02	5.634E-03	2.583E-03	-1.987E+02	-4.364E-02
1	2	I	-1.419E-03	-2.013E+02	-5.945E-03	6.027E-03	-1.419E-03	-2.013E+02	-5.945E-03
1	2	J	-1.558E-03	-2.013E+02	-5.865E-03	5.923E-03	-1.558E-03	-2.013E+02	-5.865E-03
1	2	K	3.687E-03	-2.013E+02	-7.071E-03	5.591E-03	3.687E-03	-2.013E+02	-7.071E-03
1	2	L	3.825E-03	-2.013E+02	-7.268E-03	5.696E-03	3.825E-03	-2.013E+02	-7.268E-03
2	1	I	1.931E-03	-1.988E+02	-3.367E-02	-3.542E-03	1.931E-03	-1.988E+02	-3.367E-02
2	1	J	1.223E-03	-1.990E+02	-3.305E-02	-3.463E-03	1.223E-03	-1.990E+02	-3.305E-02
2	1	K	1.761E-03	-1.990E+02	-4.236E-02	-5.358E-03	1.762E-03	-1.990E+02	-4.236E-02
2	1	L	2.469E-03	-1.988E+02	-4.316E-02	-5.436E-03	2.469E-03	-1.988E+02	-4.316E-02
2	2	I	-1.833E-03	-2.013E+02	-6.185E-03	-5.247E-03	-1.833E-03	-2.013E+02	-6.185E-03
2	2	J	-1.970E-03	-2.013E+02	-6.110E-03	-5.152E-03	-1.969E-03	-2.013E+02	-6.110E-03
2	2	K	3.840E-03	-2.013E+02	-7.192E-03	-5.486E-03	3.841E-03	-2.013E+02	-7.192E-03
2	2	L	3.977E-03	-2.013E+02	-7.391E-03	-5.581E-03	3.978E-03	-2.013E+02	-7.391E-03

ATTACHMENT C – O-RING INTERFACE LOADS

Axisymmetric nodal forces on lid from O-ring pressure

Inner O-ring

Node number	Node radius	Mean radius	Force/pressure factor	Load case 1 Pressure	Load case 1 Force	Load case 2 Pressure	Load case 2 Force
143	2.69812		0.053659565	198.825	10.66886299	201.3	10.80167042
		2.717935					
144	2.73775		0.108483245	198.825	21.56918112	201.3	21.83767716
		2.75756					
145	2.77737		0.110053385	198.825	21.88136433	201.3	22.15374646
		2.797185					
146	2.817		0.055622538	198.825	11.0591511	201.3	11.19681688

Outer O-ring

Node number	Node radius	Mean radius	Force/pressure factor	Load case 1 Pressure	Load case 1 Force	Load case 2 Pressure	Load case 2 Force
149	2.942		0.061513619	234.825	14.44493549	237.1	14.58487897
		2.962835					
150	2.98367		0.124314506	234.825	29.19215396	237.1	29.47496946
		3.0045					
151	3.02533		0.126050479	234.825	29.59980364	237.1	29.88656848
		3.046165					
152	3.067		0.063683896	234.825	14.95457097	237.1	15.09945183

ATTACHMENT D – INTERFACE LOADS ON NUT

Matching interface pressure loads

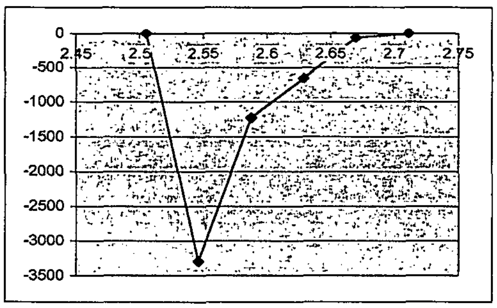
Load Case 1

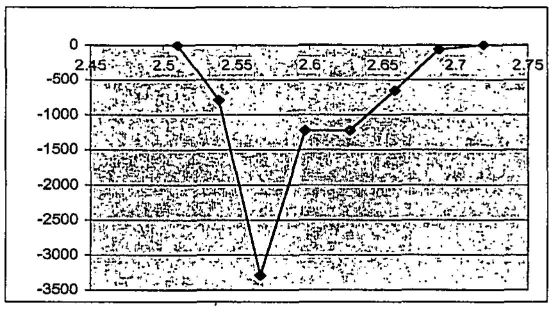
Side 1

Index	Radius	Szz	FORCEz	Force/Rad
0	2.50507	0		
1	2.54629	-3300.16	-136.0161	-346.3364
2	2.5875	-1230.75	-50.71921	-131.2359
3	2.62871	-662.77	-27.31275	-71.7973
4	2.66992	-65.6015	-2.703438	-7.217963
5	2.71113	0		
Sum			-216.7515	-556.5876

Side 2

Index	Radius	Szz	FORCEz	Force/Rad
	2.50964	0		
	2.53798	-800	-22.668	-57.53093
	2.56631	-3300.16	-97.27222	-249.6307
	2.59693	-1230.75	-37.67941	-97.85079
	2.62754	-1230.75	-37.67941	-99.00416
	2.65816	-662.77	-20.2907	-53.93594
	2.68877	-65.6015	-2.00839	-5.400099
	2.71939	0		
Sum			-217.5981	-563.3526





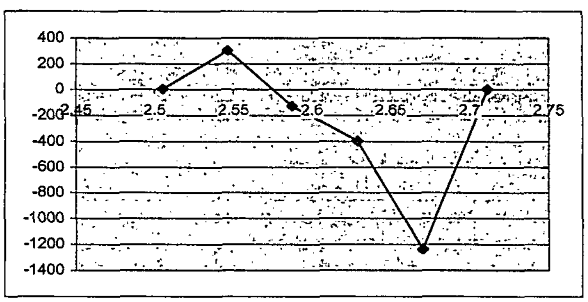
Load Case 2

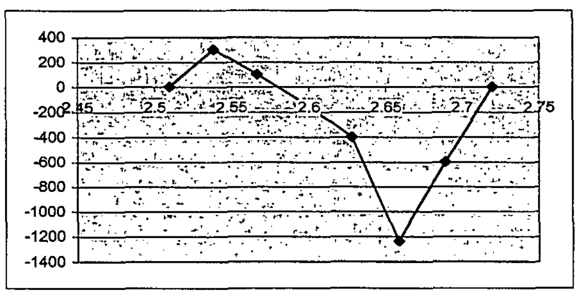
Side 1

Index	Radius	Szz	FORCEz	Force/Rad
0	2.50507	0		
1	2.54629	301.824	12.43968	31.67502
2	2.5875	-132.484	-5.459666	-14.12688
3	2.62871	-398.673	-16.42931	-43.1879
4	2.66992	-1240.54	-51.12265	-136.4934
5	2.71113	0		
Sum			-60.57196	-162.1332

Side 2

Index	Radius	Szz	FORCEz	Force/Rad
	2.50964	0		
	2.53798	301.824	8.552183	21.70527
	2.56631	100	2.9475	7.564199
	2.59693	-132.484	-4.055998	-10.53314
	2.62754	-398.673	-12.20537	-32.07011
	2.65816	-1240.54	-37.97913	-100.9546
	2.68877	-600	-18.369	-49.39002
	2.71939	0		
Sum			-61.10982	-163.6784





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.

4.0 ANALYSES AND/OR CALCULATIONS

The previous analysis (Hammond) followed ASME Code rules to validate the vessel design under a bounding internal pressure of 101.5 psi. The design margin of the vessel, including the vessel body, the lid, and the retaining nut but not including threads on the nut or vessel body, was limited by stress intensity calculated at the side wall to bottom transition of the vessel. The actual maximum expected internal pressure is 17.786 psia or 17.786 psia – 14.7 psia = 3.1 psig. Away from the contact region between the lid and vessel body, stresses are proportional to pressure so the stress in the body and at the center of the lid will be reduced to 3.1 psi/101.5 psi = 0.0305 or 3.05% of values calculated previously. The design margin in the vessel becomes limited by stresses in the clamping region primarily due to gasket seating load or the load produced by tightening the nut. These calculations determine the load from torquing the nut and their effects on stress in the vessel components in the contact or clamping region.

4.1 TIGHTENING TORQUE

The specified nut torque is 120 +/- 5 ft.-lb. From Laughtner & Hargan, the ratio of axial force, P (lb.), to torque, T (in.-lb.) is

$$P/T = 2/(D\nu + d_p\, m), \text{ where}$$

D = mean bearing diameter of nut (in.),

dp = pitch diameter of screw thread (in.),

ν = coefficient of friction between nut and bearing surface,

$$m = \frac{\tan(\beta + \phi)}{\cos\alpha}, \text{ where}$$

α = one-half of thread profile angle (degrees),

β = helix angle (degrees), and

ϕ = friction angle the tangent of which is the friction coefficient.

The threads are 7 inch nominal diameter with 8 threads per inch or having a pitch of 0.125 in. From B1.9 the pitch diameter is

$$d_p = 7\,\text{in.} - 0.6(0.125\,\text{in.}) = 6.93\,\text{in.}$$

The helix angle on the pitch diameter is

$$\beta = \arctan\frac{0.125\,\text{in.}}{\pi(6.93\,\text{in.})} = 0.329^\circ.$$

The thread profile angle at the mating surfaces is 7° so $\alpha = 3.5^\circ$.

The mean effective bearing diameter of the nut is about 5.8 inches. That is D = 5.8 in.

The referenced drawing has the note: "During installation of container vessel lid assembly, apply a light coat of Krytox grease to the threads and under the nut." A typical value for coefficient of friction for lubricated threads is 0.11. In this case

$\phi = \arctan(0.11) = 6.3$.

$$m = \frac{\tan(0.329^\circ + 6.3^\circ)}{\cos(3.5^\circ)} = 0.12 .$$

$$P/T = 2/(5.8\,\text{in.}(0.11) + 6.93\,\text{in.}(0.12)) = 1.36 .$$

The maximum and the minimum force, assuming that the friction coefficient 0.11 is correct are

Pmax = 1.36 T = 1.36 (125 ft.-lb)(12 in./ft.) = 2,000 lb., rounding to 2 significant figures, and

Pmin = 1.36 (115 ft.-lb.)(12 in./ft.) = 1,900 lb.

According to Hammond the force required to seat the gaskets is
$W_{m2} = 20\,\text{lb./in.}\,\pi[(5.359\,\text{in.} + 0.139\,\text{in.}) + (5.859\,\text{in.} + 0.139\,\text{in.})] = 722.3\,\text{lb}$ and

the load due to the maximum allowable pressure, 101.5 psig, to the outer edge of the inner O-ring groove is

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

The sum of gasket seating and pressure forces is 3,244 lb. so the specified torque is not adequate for the bounding pressure. However, the highest expected internal pressure is 17.786 psia which is (17.786 psia – 14.7 psia =) 3.1 psig so

$$W_{m1} = \pi \frac{3.1\,\text{psig}(5.624\,\text{in.})^2}{4} = 77\,\text{lb}.$$

The sum of gasket seating force and actual pressure force is 799 lb and there is a large margin on torque required to maintain a tight gasket and consequently the required torque is not sensitive to the coefficient of friction.

The minimum cross section area of the CV subject to the axial force from torquing the nut is at the undercut just below the threads. The inside diameter at the undercut is 6.85 in. +2(0.09 in.) = 7.03 in. The outside diameter in the same plane is 7.50 in. The minimum cross section area considering the tolerances listed on the drawing is $\pi((7.50\,\text{in.} - 0.01\,\text{in.})^2 - (7.03\,\text{in.} + 0.01\,\text{in.})^2))/4 = 5.14\,\text{in}^2$.

The average axial stress due to the force due to maximum torque at this section is

$\overline{\sigma}_{torque} = 2{,}000\ \text{lb.} / 5.14\ \text{in}^2 = 389\ \text{psi}.$

The maximum diameter at the root of a thread on the CV is 7.04 in. That is called the maximum major diameter of the internal thread which per B1.9 is D – h + PDtol. + 0.80803 p, where D is the major diameter (7 in.), h is the basic height of thread engagement (0.6 p), PDtol. is tolerance on pitch diameter (0.0101 in.), and p is pitch (0.125 in.). The cross section area at the root of the thread is thus the same as the minimum area at the undercut (i.e. 7.03 in. + 0.01 in. including tolerance) and the average stress is the same.

The finite element model used by Hammond to evaluate pressure resistance was modified to simulate the effect of the axial force due to torquing the nut. The section of the vessel between the flange surface and the threads was forced to shrink in the axial direction by applying an artificial temperature drop of 100° F. and manipulating the axial coefficient of thermal expansion to produce an axial force of 2,000 lb. Fig. 1 shows the effected region of the vessel with dots at the locations where axial stresses were recorded. The O-ring elements were removed and the entire flange surface was held in place by stiff axial spring elements. Nodal axial stresses were obtained across the two horizontal sections. There were two stresses calculated at each point, one above and one below the section boundary. The stress in the section without the temperature-dependent properties was recorded to avoid including thermal strain in the stress calculation. The results from the final run are shown on the spreadsheet along with the axial stress calculated at each point across the two sections in Appendix 1.

The net axial forces across each section were calculated by multiplying the axial stress over the tributary area. There was a slight but acceptable difference (4%) between the upper and lower sections attributed to model coarseness. The net force across the section with the highest axial stress was about 2% greater than 2000 lb.

The plot of axial stress shown in Appendix 1 clearly indicates that the peak stress at the left edge is higher than an extrapolated equivalent linear bending stress. The value of peak stress due to preload from torque, 3,476 psi, is so low that we can substitute this peak stress for the sum of membrane and bending stress in combination with axial stress from other loads.

The gasket seating force between the lid and CV body is the sum of gasket seating forces at both O-rings or 722.3 lb. total. The pressure force due to the 101.5 psig from the earlier calculation over the area to the back side of the inner O-ring groove is

$$F_P := 101.5\,\text{psi}\,\pi(2.817\,\text{in.})^2 = 2530\,\text{lb.}$$

In general, stress intensities are not linear functions of applied force but in our case of the axial force due to torque on the nut alone, stress intensities will increase by the ratio 2000 lb./722.3 lb. = 2.77 . The calculated peak stress intensity due to gasket seating load alone (Load Case 2) were highest near points of high compression that would be affected by the applied torque. The peak values were 872 psi in the lid and 2224 psi in the nut (Hammond, pp. 18, 20). The stresses in these components due to torque would be 2.77(872 psi) = 2415 psi in the lid and 2.77(2224 psi) = 6158 psi in the nut.

Bending or radial stress near the center of the lid and stresses in the vessel body away from the contact region will be reduced to about 3.05% of previously calculated values.

The effect of an internal 3.1 psig pressure plus the torque is shown in Fig. 3. Maximum stress intensity is 3501 psi. This is in the same location as for the pressure plus gasket seat case, in the transition between the side and bottom of the vessel. The axial stress in this region due to 3.1 psi pressure and torque is shown on Fig. 4. The peak axial stress is 3714 psi. The slight pressure causes just a slight increase in stress over the case with torque alone. The stress intensities in the clamping regions of the lid and nut will become about (3714 psi/3476 psi) 2415 psi = 2580 psi and (3714 psi/3476 psi) 6158 psi = 6580 psi, respectively.

4.2 DIFFERENTIAL THERMAL EXPANSION

The range of temperatures to which the CV may be exposed is -40° F. to 190.06° F. The average thermal expansion coefficient for the 304 material of the CV between 70 and 200 F. is 8.9 10^{-6} in./in./° F. and greater for higher upper temperatures per Section II. From the HP Alloys web site the average thermal expansion coefficient of the Nitronic 60 material of the nut between 75 and 200 F. is 8.8 10^{-6} in./in./° F. and greater for higher upper temperatures. Since the temperatures on opposite sides of the thread mating surface are expected to be the same an upper bound on the stress due to differential thermal expansion is

$\sigma_t = E_c \Delta T(\alpha_{CV} - \alpha_N)$, where E_c is the cold elastic modulus of either part, T is temperature, and α is average thermal expansion coefficient.

In the CV the stress, using a modulus interpolated from Table TM-1 in Section II, is

$$\sigma_{tCV} = 28.8\times10^6\,\text{psi}(190.06^\circ - (-40^\circ))(8.9\times10^{-6}\,\text{in./in./}^\circ - 8.8\times10^{-6}\,\text{in./in/}^\circ)$$
$$= 663\,\text{psi}.$$

The nut material has a slightly lower modulus listed so the stress in the nut will be slightly less. The room temperature modulus of the nut material is 26.2×10^6 psi per the HP Alloy website. The cold temperature modulus is not available but an approximation is obtained by comparing the modulus of Nitronic 60 at room temperature with the modulus of 304 at room temperature. From Table TM-1, the modulus of 304 at 70F. is 28.3 × 106 psi. Stress in the nut at the threads is about

$$\sigma_{tN} = \frac{26.2\times10^6\,\text{psi}}{28.3\times10^6\,\text{psi}}663\,\text{psi} = 613\,\text{psi}.$$

The CV material has the higher thermal expansion coefficient so the effect of temperature increase is to reduce preload on the lid. Consider the mid-height of the threads to be fixed. The fixed plane is 1.100 in. – 0.55 in. / 2 = 0.825 in. above the mating plane. The lid is 0.5 in. thick under the nut and the lid will grow the same amount as the CV. The nut has 0.325 in. of material below the fixed plane and the difference in growth between the CV and the nut is

$$0.325\,\text{in.}(190.06^\circ - (-40^\circ))(8.9\times10^{-6}\,\text{in./in./}^\circ - 8.8\times10^{-6}\,\text{in./in./}^\circ)$$
$$= 0.0000075\,\text{in.}$$

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	$\pi(3.98\text{in.})^2(0.56\text{in.})/4$	6.97
Middle	$\pi(6.741\text{in.})^2(0.500\text{in.})/4$	17.84
Bottom	$\pi(5.00\text{in.})^2(0.05\text{in.})/4$	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.

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 9 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

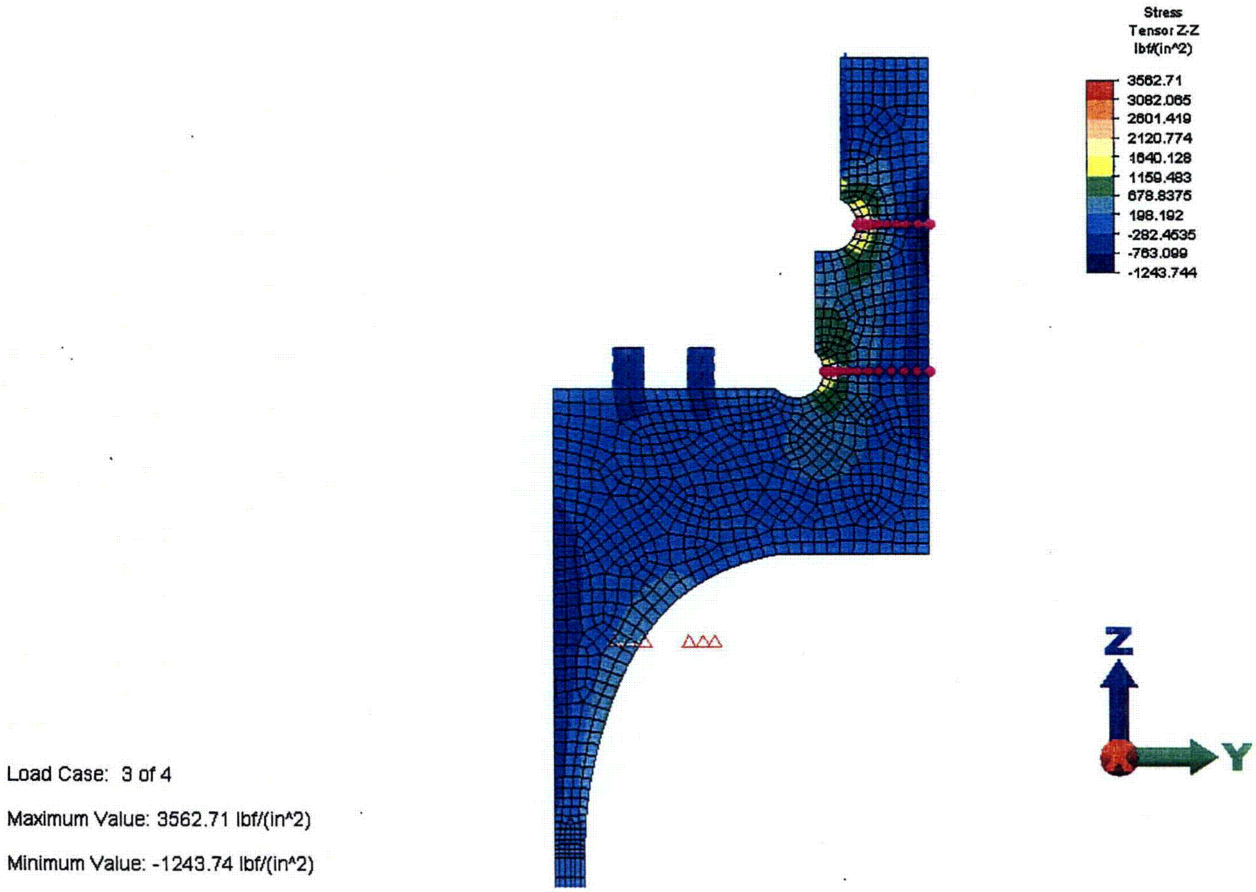


Fig. 1 – Axial Stress Due to Torque Load in Containment Vessel Neck

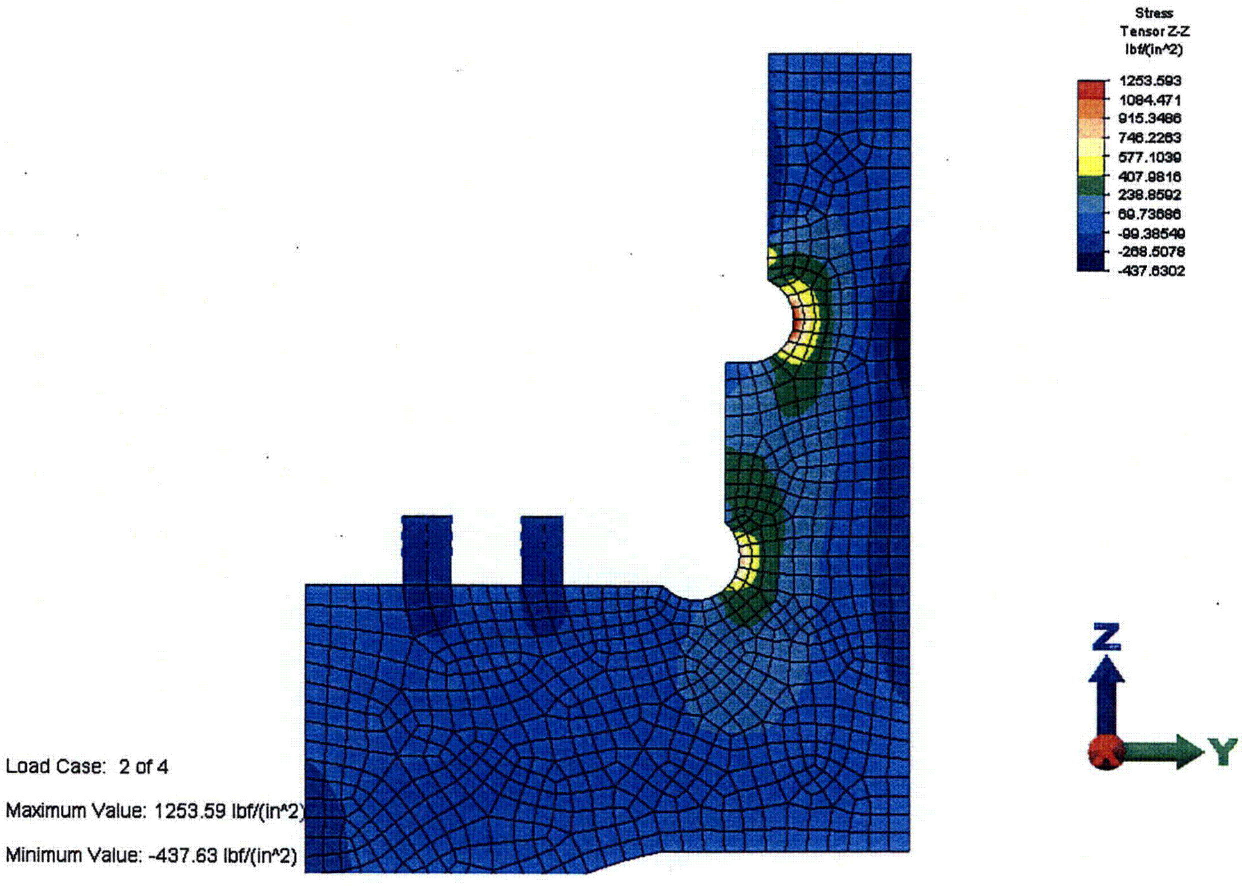


Fig. 2 – Axial Stress below the Threads in the Containment Vessel due to Gasket Seating Load

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 11 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

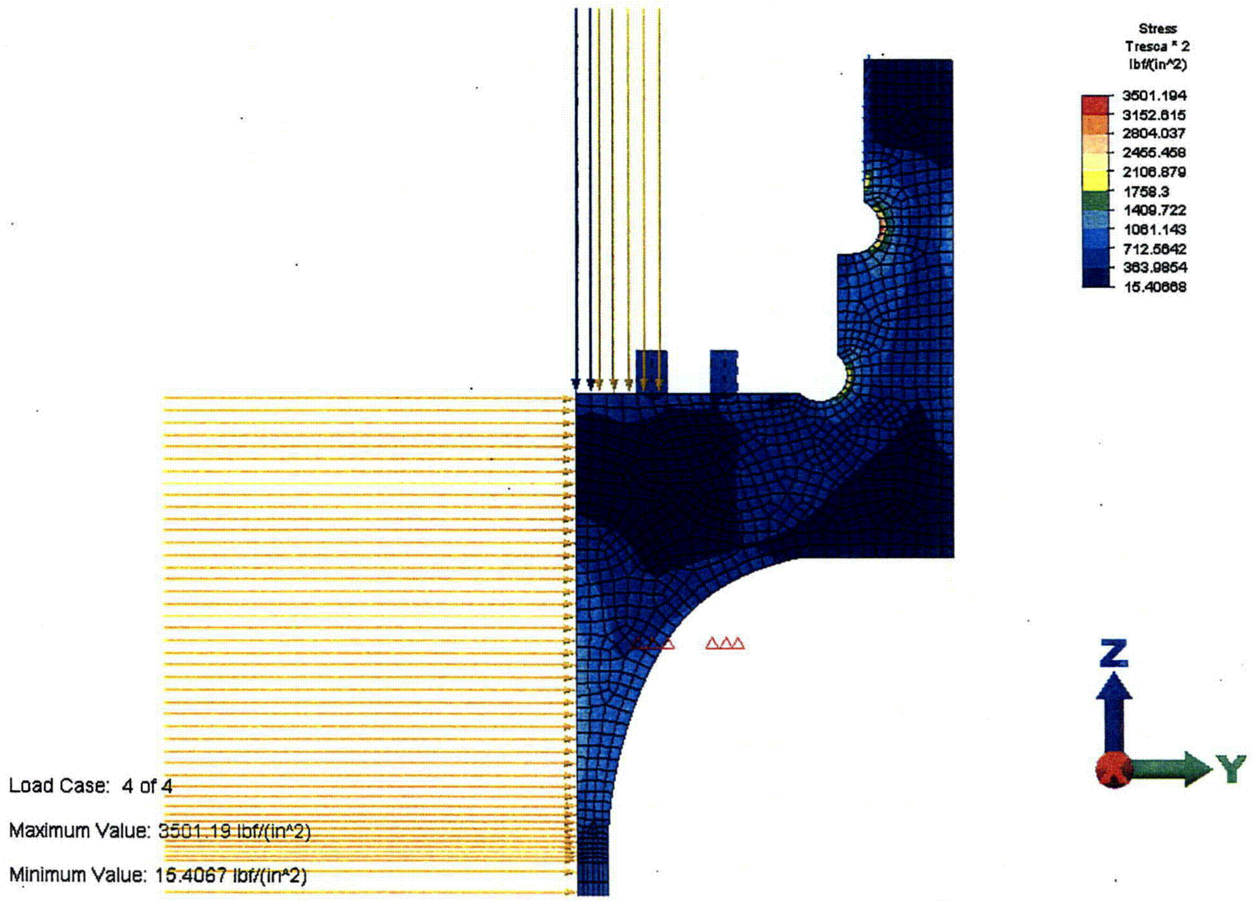


Fig. 3 –Stress Intensity below the Threads in the Containment Vessel due to 3.1 psi Pressure and Torque Loads

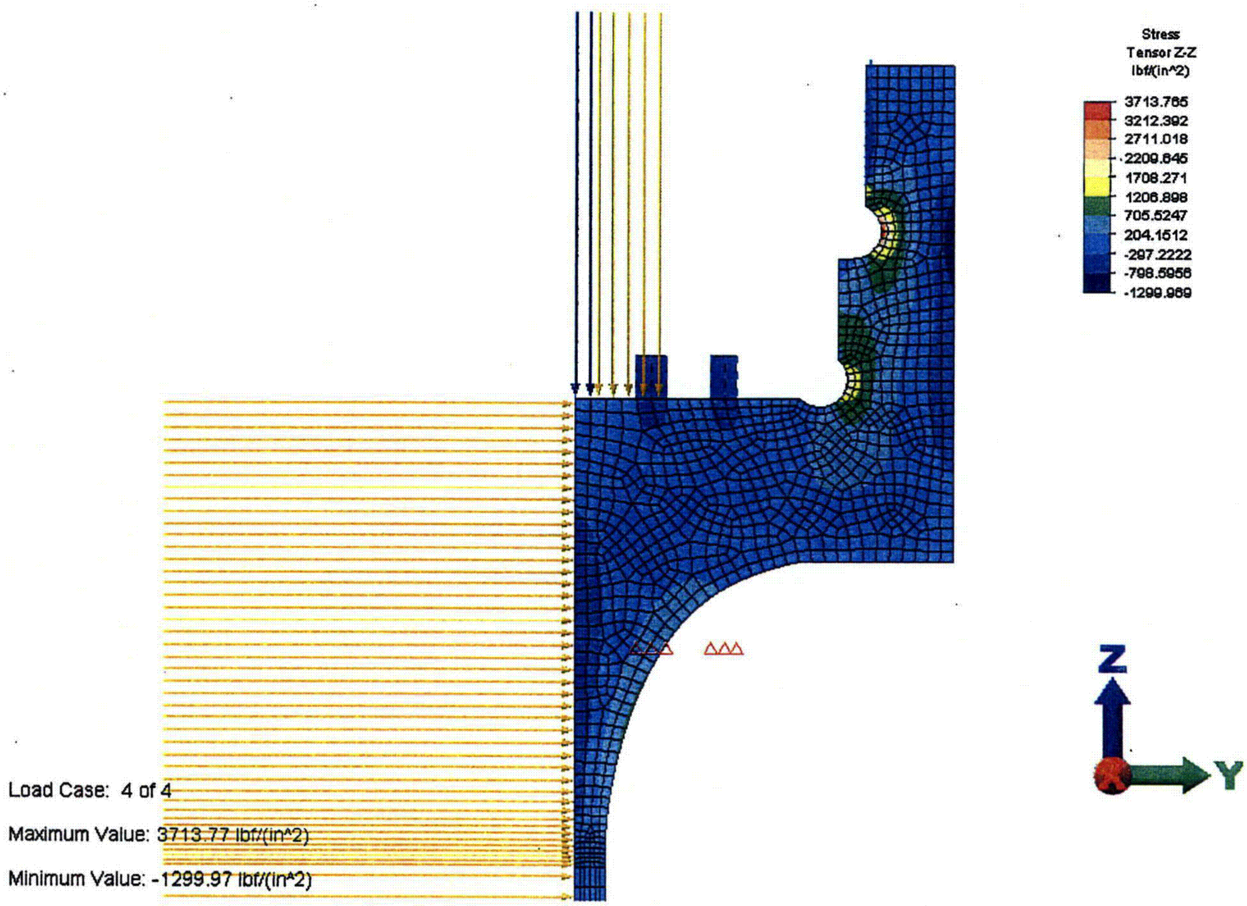


Fig. 4 – Axial Stress in Containment Vessel Due to 3.1 psi Pressure and Torque

Appendix 1 – Axial Stresses across Neck of ES-3100 due to Torque

Top Section

```
Current Load Case = 3

Node # 1894 ( X = 0, Y = 3.515, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.51496, Z = 9.44997

    Displacement = DX: 0, DY: -4.55757e-005, DZ: -2.7064e-005, Magnitude: 5.30057e-005

    appears in 2 Elements

    Part: 8     Element: 1

    Current Result Value: 3476.397428 lbf/(in^2)

    Part: 6     Element: 152

    Current Result Value: 3562.710297 lbf/(in^2)

Node # 1895 ( X = 0, Y = 3.53702, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.53697, Z = 9.44998

    Displacement = DX: 0, DY: -4.64674e-005, DZ: -1.54912e-005, Magnitude: 4.89816e-005

    appears in 4 Elements

    Part: 8     Element: 1

    Part: 8     Element: 2

    Current Result Value: 2076.571725 lbf/(in^2)

    Part: 6     Element: 151

    Part: 6     Element: 152

    Current Result Value: 2150.404851 lbf/(in^2)

Node # 1896 ( X = 0, Y = 3.55903, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.55898, Z = 9.44998

    Displacement = DX: 0, DY: -4.70825e-005, DZ: -1.69066e-005, Magnitude: 5.0026e-005

    appears in 4 Elements

    Part: 8     Element: 2

    Part: 8     Element: 3

    Current Result Value: 1338.334401 lbf/(in^2)
```

```
    Part: 6    Element: 150

    Part: 6    Element: 151

    Current Result Value: 1388.726762 lbf/(in^2)

Node # 1897 ( X = 0, Y = 3.58545, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.5854, Z = 9.44998

    Displacement = DX: 0, DY: -4.7175e-005, DZ: -1.82265e-005, Magnitude: 5.05735e-005

    appears in 4 Elements

    Part: 8    Element: 3

    Part: 8    Element: 4

    Current Result Value: 815.1134205 lbf/(in^2)

    Part: 6    Element: 149

    Part: 6    Element: 150

    Current Result Value: 856.9278605 lbf/(in^2)

Node # 1898 ( X = 0, Y = 3.61186, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.61182, Z = 9.44998

    Displacement = DX: 0, DY: -4.7039e-005, DZ: -1.97662e-005, Magnitude: 5.10232e-005

    appears in 4 Elements

    Part: 8    Element: 4

    Part: 8    Element: 5

    Current Result Value: 422.3549006 lbf/(in^2)

    Part: 6    Element: 148

    Part: 6    Element: 149

    Current Result Value: 454.1958936 lbf/(in^2)

Node # 1899 ( X = 0, Y = 3.64356, Z = 9.45 )

    Displaced Position : X = 0, Y = 3.64352, Z = 9.44998

    Displacement = DX: 0, DY: -4.6803e-005, DZ: -2.12778e-005, Magnitude: 5.14127e-005

    appears in 4 Elements

    Part: 8    Element: 5
```

```
    Part: 8     Element: 6
    Current Result Value: 60.92361234 lbf/(in^2)
    Part: 6     Element: 147
    Part: 6     Element: 148
    Current Result Value: 92.87579812 lbf/(in^2)
Node # 1900 ( X = 0, Y = 3.67526, Z = 9.45 )
    Displaced Position : X = 0, Y = 3.67522, Z = 9.44998
    Displacement = DX: 0, DY: -4.64719e-005, DZ: -2.30637e-005, Magnitude: 5.18804e-005
    appears in 4 Elements
    Part: 6     Element: 145
    Part: 6     Element: 147
    Current Result Value: -276.2872177 lbf/(in^2)
    Part: 8     Element: 6
    Part: 8     Element: 7
    Current Result Value: -291.8618414 lbf/(in^2)
Node # 1901 ( X = 0, Y = 3.71263, Z = 9.45 )
    Displaced Position : X = 0, Y = 3.71258, Z = 9.44997
    Displacement = DX: 0, DY: -4.6099e-005, DZ: -2.48703e-005, Magnitude: 5.23798e-005
    appears in 4 Elements
    Part: 8     Element: 7
    Part: 8     Element: 8
    Current Result Value: -690.1878235 lbf/(in^2)
    Part: 6     Element: 145
    Part: 6     Element: 146
    Current Result Value: -699.5449043 lbf/(in^2)
Node # 1902 ( X = 0, Y = 3.75, Z = 9.45 )
    Displaced Position : X = 0, Y = 3.74996, Z = 9.44997
    Displacement = DX: 0, DY: -4.48856e-005, DZ: -2.93433e-005, Magnitude: 5.3626e-005
```

```
    appears in 2 Elements

    Part: 8    Element: 8

    Current Result Value: -1189.038154 lbf/(in^2)

    Part: 6    Element: 146

    Current Result Value: -1243.744425 lbf/(in^2)
```

Lower Section

```
Current Load Case = 3

Node # 1718 ( X = 0, Y = 3.4065, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.40646, Z = 9.03102

    Displacement = DX: 0, DY: -3.86154e-005, DZ: 0.0710243, Magnitude: 0.0710243

    appears in 2 Elements

    Part: 6    Element: 1

    Current Result Value: 2381.970074 lbf/(in^2)

    Part: 3    Element: 713

    Current Result Value: 2573.760605 lbf/(in^2)

Node # 1719 ( X = 0, Y = 3.43091, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.43087, Z = 9.03103

    Displacement = DX: 0, DY: -3.82805e-005, DZ: 0.071027, Magnitude: 0.071027

    appears in 4 Elements

    Part: 6    Element: 1

    Part: 6    Element: 2

    Current Result Value: 1429.725908 lbf/(in^2)

    Part: 3    Element: 712

    Part: 3    Element: 713

    Current Result Value: 1507.238598 lbf/(in^2)
```

```
Node # 1720 ( X = 0, Y = 3.45532, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.45529, Z = 9.03102

    Displacement = DX: 0, DY: -3.93058e-005, DZ: 0.0710167, Magnitude: 0.0710167

    appears in 4 Elements

    Part: 3    Element: 711

    Part: 3    Element: 712

    Current Result Value: 1015.779644 lbf/(in^2)

    Part: 6    Element: 2

    Part: 6    Element: 3

    Current Result Value: 1035.108104 lbf/(in^2)

Node # 1721 ( X = 0, Y = 3.48462, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.48458, Z = 9.03103

    Displacement = DX: 0, DY: -3.78762e-005, DZ: 0.0710297, Magnitude: 0.0710297

    appears in 4 Elements

    Part: 3    Element: 710

    Part: 3    Element: 711

    Current Result Value: 699.5787633 lbf/(in^2)

    Part: 6    Element: 3

    Part: 6    Element: 4

    Current Result Value: 752.6151572 lbf/(in^2)

Node # 1722 ( X = 0, Y = 3.51391, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.51388, Z = 9.03103

    Displacement = DX: 0, DY: -3.73704e-005, DZ: 0.0710323, Magnitude: 0.0710323

    appears in 4 Elements

    Part: 3    Element: 707

    Part: 3    Element: 710

    Current Result Value: 479.8616501 lbf/(in^2)

    Part: 6    Element: 4
```

```
    Part: 6     Element: 5

    Current Result Value: 524.8054716 lbf/(in^2)

Node # 1723 ( X = 0, Y = 3.54907, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.54903, Z = 9.03101

    Displacement = DX: 0, DY: -3.89625e-005, DZ: 0.0710096, Magnitude: 0.0710096

    appears in 4 Elements

    Part: 3     Element: 704

    Part: 3     Element: 707

    Current Result Value: 286.7099034 lbf/(in^2)

    Part: 6     Element: 5

    Part: 6     Element: 6

    Current Result Value: 319.4018001 lbf/(in^2)

Node # 1724 ( X = 0, Y = 3.58422, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.58418, Z = 9.03101

    Displacement = DX: 0, DY: -3.94127e-005, DZ: 0.071011, Magnitude: 0.071011

    appears in 4 Elements

    Part: 3     Element: 704

    Part: 3     Element: 705

    Current Result Value: 104.2072763 lbf/(in^2)

    Part: 6     Element: 6

    Part: 6     Element: 7

    Current Result Value: 126.0936862 lbf/(in^2)

Node # 1725 ( X = 0, Y = 3.62567, Z = 8.96 )

    Displaced Position : X = 0, Y = 3.62563, Z = 9.03101

    Displacement = DX: 0, DY: -3.94951e-005, DZ: 0.0710126, Magnitude: 0.0710126

    appears in 4 Elements

    Part: 6     Element: 7

    Part: 6     Element: 8
```

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 19 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

```
    Current Result Value: -69.65167919 lbf/(in^2)
    Part: 3    Element: 705
    Part: 3    Element: 706
    Current Result Value: -87.34285327 lbf/(in^2)
Node # 1726 ( X = 0, Y = 3.66711, Z = 8.96 )
    Displaced Position : X = 0, Y = 3.66707, Z = 9.03101
    Displacement = DX: 0, DY: -3.94338e-005, DZ: 0.0710146, Magnitude: 0.0710146
    appears in 4 Elements
    Part: 6    Element: 8
    Part: 6    Element: 9
    Current Result Value: -274.1379622 lbf/(in^2)
    Part: 3    Element: 706
    Part: 3    Element: 708
    Current Result Value: -286.8211743 lbf/(in^2)
Node # 1727 ( X = 0, Y = 3.70856, Z = 8.96 )
    Displaced Position : X = 0, Y = 3.70852, Z = 9.03102
    Displacement = DX: 0, DY: -3.91153e-005, DZ: 0.0710191, Magnitude: 0.0710191
    appears in 4 Elements
    Part: 6    Element: 9
    Part: 6    Element: 10
    Current Result Value: -489.6421277 lbf/(in^2)
    Part: 3    Element: 708
    Part: 3    Element: 709
    Current Result Value: -498.9915546 lbf/(in^2)
Node # 1728 ( X = 0, Y = 3.75, Z = 8.96 )
    Displaced Position : X = 0, Y = 3.74996, Z = 9.03102
    Displacement = DX: 0, DY: -3.89012e-005, DZ: 0.0710215, Magnitude: 0.0710215
    appears in 2 Elements
```

```
Part: 6     Element: 10

Current Result Value: -726.5076374 lbf/(in^2)

Part: 3     Element: 709

Current Result Value: -737.209287 lbf/(in^2)
```

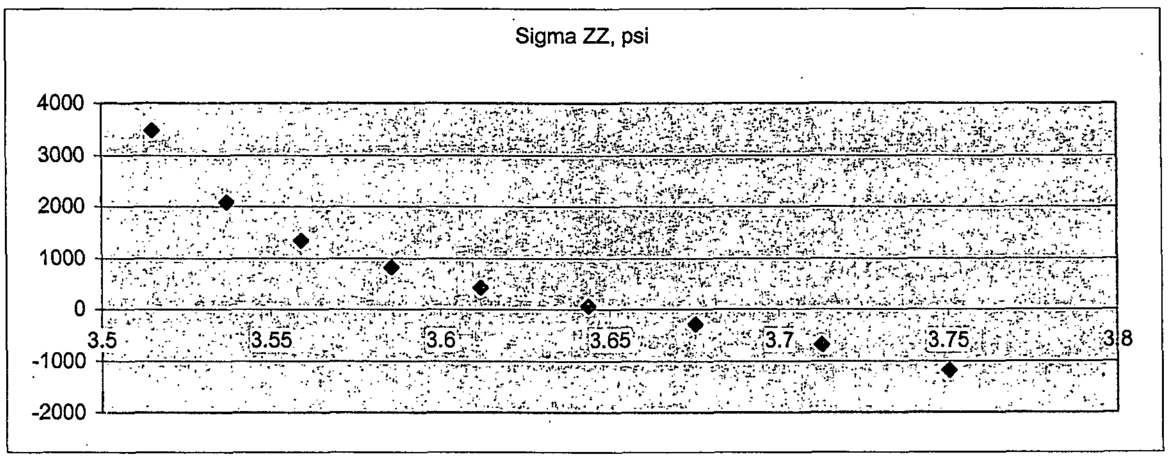
GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 21 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

Appendix 1 - Axial stress across neck of ES-3100 CV due to torque

Y, in.	Sigma ZZ, psi	Delta R, in.	Force, lb.	Force (hard way), lb.
Top section - Part 8				
3.515	3476.397428	0.01101	845.3215421	846.6454383
3.53702	2076.571725	0.022015	1015.974973	1015.974255
3.55903	1338.334401	0.024215	724.7039558	724.9284512
3.58545	815.1134205	0.026415	485.0563535	485.0560153
3.61186	422.3549006	0.029055	278.4897363	278.5917067
3.64356	60.92361234	0.0317	44.21307309	44.21307309
3.67526	-291.8618414	0.034535	-232.7580525	-232.8478243
3.71263	-690.1878235	0.03737	-601.6610939	-601.6610939
3.75	-1189.038154	0.018685	-523.4799217	-522.1757588
		Sum	2035.860566	2038.724263
Lower section - Part 3				
3.4065	2573.760605	0.012205	672.3481194	673.5525828
3.43091	1507.238598	0.02441	793.1201445	793.1201445
3.45532	1015.779644	0.026855	592.2332744	592.4428079
3.48462	699.5787633	0.029295	448.7096535	448.7093316
3.51391	479.8616501	0.032225	341.4125422	341.5551249
3.54907	286.7099034	0.035155	224.7626947	224.7625364
3.58422	104.2072763	0.0383	89.88171407	89.92121045
3.62567	-87.34285327	0.041445	-82.46461971	-82.46456285
3.66711	-286.8211743	0.041445	-273.8969268	-273.8971135
3.70856	-498.9915546	0.041445	-481.8928886	-481.8925638
3.75	-737.209287	0.02072	-359.9081529	-358.9138467
		Sum	1964.305555	1966.895652

Section difference = 0.036518771



Appendix 2 – Finite Element Data

Summary

Description

Thread Analysis

Model Information

Analysis Type - Static Stress with Linear Material Models
Units - English (in) - (lbf, in, s, deg F, deg R, V, ohm, A, in*lbf)
Model location - C:\ALGOR12\es3100CV1

Analysis Parameters Information

Load Case Multipliers

Static Stress with Linear Material Models may have multiple load cases. This allows a model to be analyzed with multiple loads while solving the equations a single time. The following is a list of load case multipliers that were analyzed with this model.

Load Case	Pressure/ Surface Forces	Acceleration/ Gravity	Displaced Boundary	Thermal	Voltage
1	1	0	1	0	0
2	0	0	1	0	0
3	0	0	0	1	0
4	0.0305	0	0	1	0

Multiphysics Information

Default Nodal Temperature	70°F
Source of Nodal Temperature	None
Time step from Heat Transfer Analysis	Last

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 23 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

Processor Information

Type of Solver	Sparse
Disable Calculation and Output of Strains	No
Calculate Reaction Forces	Yes
Invoke Banded Solver	Yes
Avoid Bandwidth Minimization	No
Stop After Stiffness Calculations	No
Displacement Data in Output File	No
Stress Data in Output File	No
Equation Numbers Data in Output File	No
Element Input Data in Output File	No
Nodal Input Data in Output File	No
Centrifugal Load Data in Output File	No

Part Information

Part ID	Part Name	Element Type	Material Name
1	Plate & shell	2-D	[Customer Defined] (Part 1)
2	Bottom corner	2-D	[Customer Defined] (Part 2)
3	Top transition	2-D	[Customer Defined] (Part 3)
4	Outer O-ring	2-D	[Customer Defined] (Part 4)
5	Inner O-ring	2-D	[Customer Defined] (Part 5)
6	Top flange neck	2-D	[Customer Defined] (Part 6)
8	Thread region	2-D	[Customer Defined] (Part 8)

Element Properties used for:

- Plate & shell
- Bottom corner
- Top transition
- Thread region

Element Type	2-D
Geometry Type	Axisymmetric
Material Model	Isotropic
Thickness	1 in
Stress Free Reference Temperature	70°F
Principle Axes Transformational Angle	0°
Nodal Order Method	Default
Nodal Order Y Coordinate	0 in
Nodal Order Z Coordinate	0 in

Element Properties used for:

- Outer O-ring
- Inner O-ring

Element Type	2-D
Geometry Type	Axisymmetric
Material Model	Isotropic
Thickness	1 in
Stress Free Reference Temperature	0°F
Principle Axes Transformational Angle	0°
Nodal Order Method	Default
Nodal Order Y Coordinate	0 in
Nodal Order Z Coordinate	0 in

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 25 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

Element Properties used for:

- Top flange neck

Element Type	2-D
Geometry Type	Axisymmetric
Material Model	Orthotropic
Thickness	1 in
Stress Free Reference Temperature	170°F
Principle Axes Transformational Angle	0°
Nodal Order Method	Default
Nodal Order Y Coordinate	0 in
Nodal Order Z Coordinate	0 in

Material Information

[Customer Defined] (Part 1) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:35:06
Material Description	Customer defined material properties
Mass Density	7.50e-4 lbf*s^2/in/in³
Modulus of Elasticity	27e6 lbf/in²
Poisson's Ratio	0.3
Thermal Coefficient of Expansion	9.2e-6 1/°F
Shear Modulus of Elasticity	10384615 lbf/in²

GENERAL DESIGN AND COMPUTATION SHEET

JOB Fatigue Analysis of ES-3100 CV Threads under Normal Conditions of Use		DATE 16 February 2005	SHEET 26 of 29
DAC NO. DAC-EA-900000-A007	REVISION NO. 0	COMPUTED C. R. Hammond	CHECKED BY M. L. Goins

[Customer Defined] (Part 2) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:36:43
Material Description	Customer defined material properties
Mass Density	7.50e-4 lbf*s^2/in/in³
Modulus of Elasticity	27e6 lbf/in²
Poisson's Ratio	0.3
Thermal Coefficient of Expansion	9.2e-6 1/°F
Shear Modulus of Elasticity	10384615 lbf/in²

[Customer Defined] (Part 3) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:38:39
Material Description	Customer defined material properties
Mass Density	7.50e-4 lbf*s^2/in/in³
Modulus of Elasticity	27e6 lbf/in²
Poisson's Ratio	0.30
Thermal Coefficient of Expansion	9.2e-6 1/°F
Shear Modulus of Elasticity	10384615 lbf/in²

GENERAL DESIGN AND COMPUTATION SHEET

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

[Customer Defined] (Part 4) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:39:52
Material Description	Customer defined material properties
Mass Density	0 lbf*s^2/in/in³
Modulus of Elasticity	1321 lbf/in²
Poisson's Ratio	0
Thermal Coefficient of Expansion	0 1/°F
Shear Modulus of Elasticity	660.5 /²

[Customer Defined] (Part 5) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:40:41
Material Description	Customer defined material properties
Mass Density	0 lbf*s^2/in/in³
Modulus of Elasticity	1122 lbf/in²
Poisson's Ratio	0
Thermal Coefficient of Expansion	0 1/°F
Shear Modulus of Elasticity	561. /²

GENERAL DESIGN AND COMPUTATION SHEET

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

[Customer Defined] (Part 6) - 2-D

Material Model	OrthotropicTempDep
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/10/14-14:27:16
Material Description	Customer defined material properties
Mass Density	7.50e-4 lbf*s^2/in/in^3
Index 1 - Temperature	170 °F
Index 1 - E1	27e6 lbf/in^2
Index 1 - E2	27e6 lbf/in^2
Index 1 - E3	27e6 lbf/in^2
Index 1 - V12	.3
Index 1 - V13	.3
Index 1 - V23	.3
Index 1 - G12	10384615 lbf/in^2
Index 1 - G13	10384615 lbf/in^2
Index 1 - G23	10384615 lbf/in^2
Index 1 - Alpha 1	0 1/°F
Index 1 - Alpha 2	1.45e-3 1/°F
Index 1 - Alpha 3	0 1/°F

[Customer Defined] (Part 8) - 2-D

Material Model	Standard
Material Source	Not Applicable
Material Source File	
Date Last Updated	2004/09/28-14:43:25
Material Description	Customer defined material properties
Mass Density	7.50e-4 lbf*s^2/in/in³
Modulus of Elasticity	27e6 lbf/in²
Poisson's Ratio	0.30
Thermal Coefficient of Expansion	9.2e-6 1/°F
Shear Modulus of Elasticity	10384615 lbf/in²

Processor Output

Processor Summary

```
ALGOR (R) Static Stress with Linear Material Models
Version 16.00-WIN 29-SEP-2004
Copyright (c) 1984-2004 ALGOR, Inc. All rights reserved.

------------------------------------------------
                        DATE: FEBRUARY 16, 2005
                        TIME: 07:55 AM
                 INPUT MODEL: C:\ALGOR12\es3100CV1

             PROGRAM VERSION: 16000001
             ALG.DLL VERSION: 13240000
       AlgConfig.DLL VERSION: 15000000
        agsdb_ar.DLL VERSION: 14000004
        amgsolve.DLL VERSION: 03220000
------------------------------------------------

      Linear Stress

1**** CONTROL INFORMATION

      number of node points       (NUMNP)    =          2061
      number of element types     (NELTYP)   =             8
      number of load cases        (LL)       =             4
```

```
     number of frequencies          (NF)      =          0
     analysis type code             (NDYN)    =          0
     equations per block            (KEQB)    =          0
     bandwidth minimization flag    (MINBND)  =          0
     gravitational constant         (GRAV)    = 3.8640E+02
     number of equations            (NEQ)     =       4092

 **** PRINT OF NODAL DATA SUPPRESSED
 **** PRINT OF EQUATION NUMBERS SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-4 ELEMENT DATA SUPPRESSED
 **** PRINT OF TYPE-7 ELEMENT DATA SUPPRESSED
 **** Hard disk file size information for processor:

     Available hard disk space on current drive =   3849.848 megabytes

1**** NODAL LOADS (STATIC) OR MASSES (DYNAMIC)
```

NODE NUMBER	LOAD CASE	X-AXIS FORCE	Y-AXIS FORCE	Z-AXIS FORCE	X-AXIS MOMENT	Y-AXIS MOMENT	Z-AXIS MOMENT
1685	1	0.000E+00	0.000E+00	-6.362E+00	0.000E+00	0.000E+00	0.000E+00
1685	4	0.000E+00	0.000E+00	-1.943E-01	0.000E+00	0.000E+00	0.000E+00
1686	1	0.000E+00	0.000E+00	-6.424E+00	0.000E+00	0.000E+00	0.000E+00
1686	4	0.000E+00	0.000E+00	-1.962E-01	0.000E+00	0.000E+00	0.000E+00

```
1**** ELEMENT LOAD MULTIPLIERS
```

load case	case A	case B	case C	case D	case E
1	1.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00
2	0.000E+00	0.000E+00	1.000E+00	0.000E+00	0.000E+00
3	0.000E+00	0.000E+00	0.000E+00	1.000E+00	0.000E+00
4	3.050E-02	0.000E+00	0.000E+00	1.000E+00	0.000E+00

APPENDIX 2.10.2

IMPACT ANALYSES OF ES-3100 DESIGN CONCEPTS USING BOROBOND AND CAT 277-4 NEUTRON ABSORBERS

Index

Part B - Design with HABC Cylinder (continued)

1.0 Problem Statement

This calculation summarizes the impact simulation computer runs made in support of the ES-3100 shipping package design effort. From the summer of 2003 through the spring of 2004 the design impact simulations were run with borobond as the neutron absorber. During the summer of 2004, the ES-3100 with the borobond neutron absorber was tested to the 10CFR71 impact requirements. In August 2004 a decision was made to change the neutron absorber material to a high alumina borated cement (HABC). The HABC material is also known as "Catalog 277-4" or just "277-4", but the HABC notation is used in this report. The August 2004 absorber change also involved some minor design changes to the configuration of the package liners surrounding the HABC material. Material testing on the HABC material occurred during the Fall of 2004. The simulation impacts were run in the late Fall of 2004.

This calculation is presented in two parts, Part A and Part B. Part A summarizes the impact simulations made for the initial borobond design. Part B summarizes the impact analyses made with the HABC design. A beginning section, Section 1.0 and an ending section, Section 9.0, address both designs. The Part A borobond design simulations are documented in Sections 2 through 5. The Part B, HABC simulations are documented in Sections 6 through 8. A detailed explanation of changes to the Part A, borobond models to develop the Part B HABC models is given in Part B, Section 6.1.

A qualitative, cross sectional view of a ES-3100 package with the initial design borobond neutron absorber (presented in Part A) is shown in Figure 1.1. The ES-3100 shipping package is a stainless steel drum with kaolite insulation material. The overall dimensions of the overpack are a height of about 44 inches and a diameter of about 19.4 inches. At the top of the overpack is a bolted lid restrained by eight, 5/8 inch welded studs. The lid restrains a removable plug filled with the kaolite material. The plug covers a cavity in which the stainless steel containment vessel (CV) is placed. The CV is about 32.9 inches tall with a 5.4 inch inside diameter and a body wall thickness of 0.1 inches. The CV closure is a flat plate constrained by a threaded ring. In the shipping package, and immediately surrounding the CV cavity is a 0.90 inch thick layer of borobond, a neutron absorbing cast material. All the kaolite and borobond materials are wrapped by stainless steel liners. In this model, there is a slight indentation (about 0.32 in) of the liner near the CV flange region into the kaolite, as can be seen in Figure 1.1.

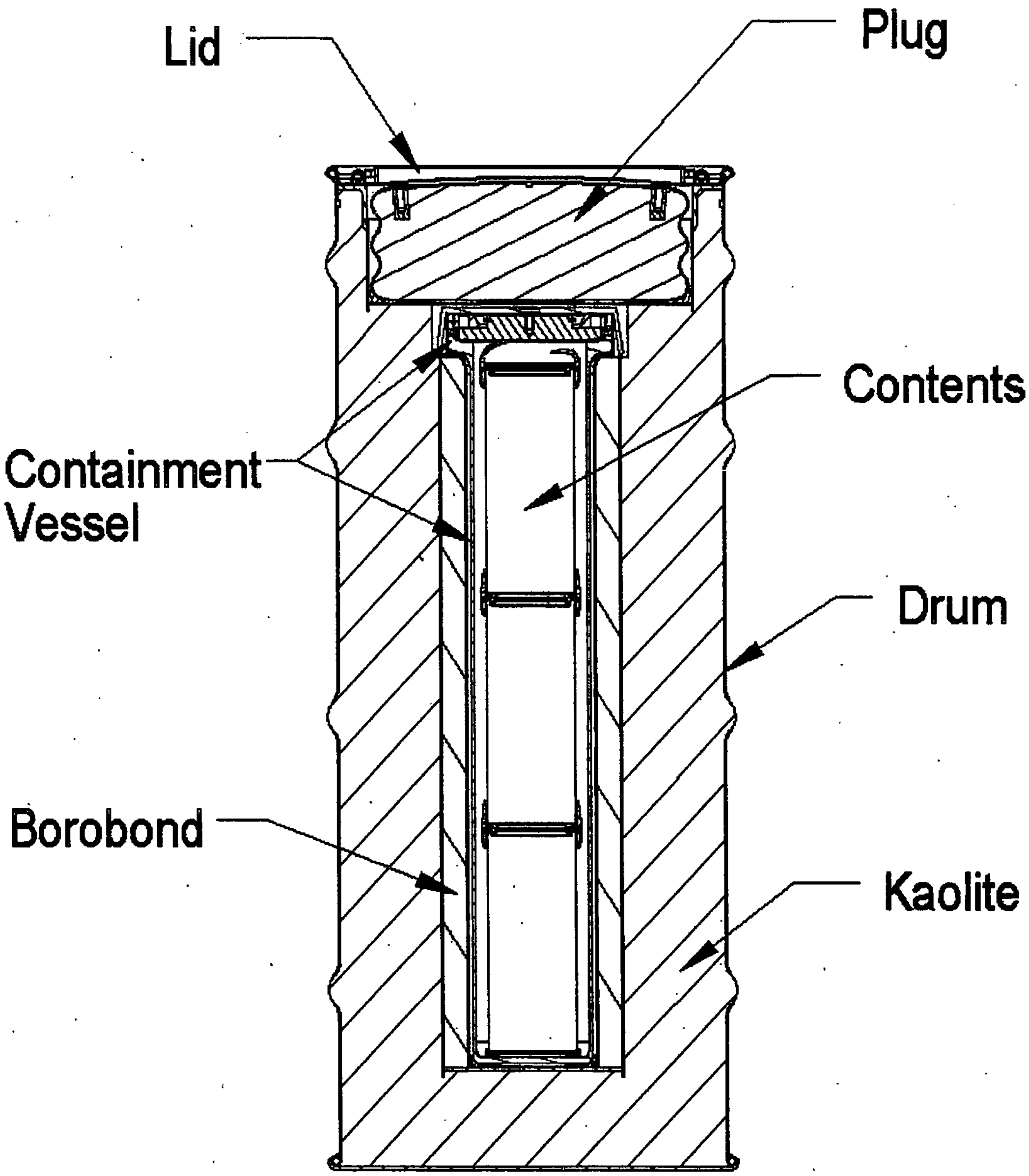


Figure 1.1 - Configuration of the Initial, Borobond Neutron Absorber ES-3100 Package, Presented in Part A

The redesigned package with the HABC (Part B) is shown in Figure 1.2. As can be qualitatively seen in the figure, the liner between the HABC and the kaolite is moved out slightly and there is no indentation into the kaolite near the CV flange. The HABC design changes are minor as shown by qualitatively comparing Figures 1.1 and 1.2. The detailed differences between the Part A borobond model and the Part B, HABC model are presented in Part B, Section 6.

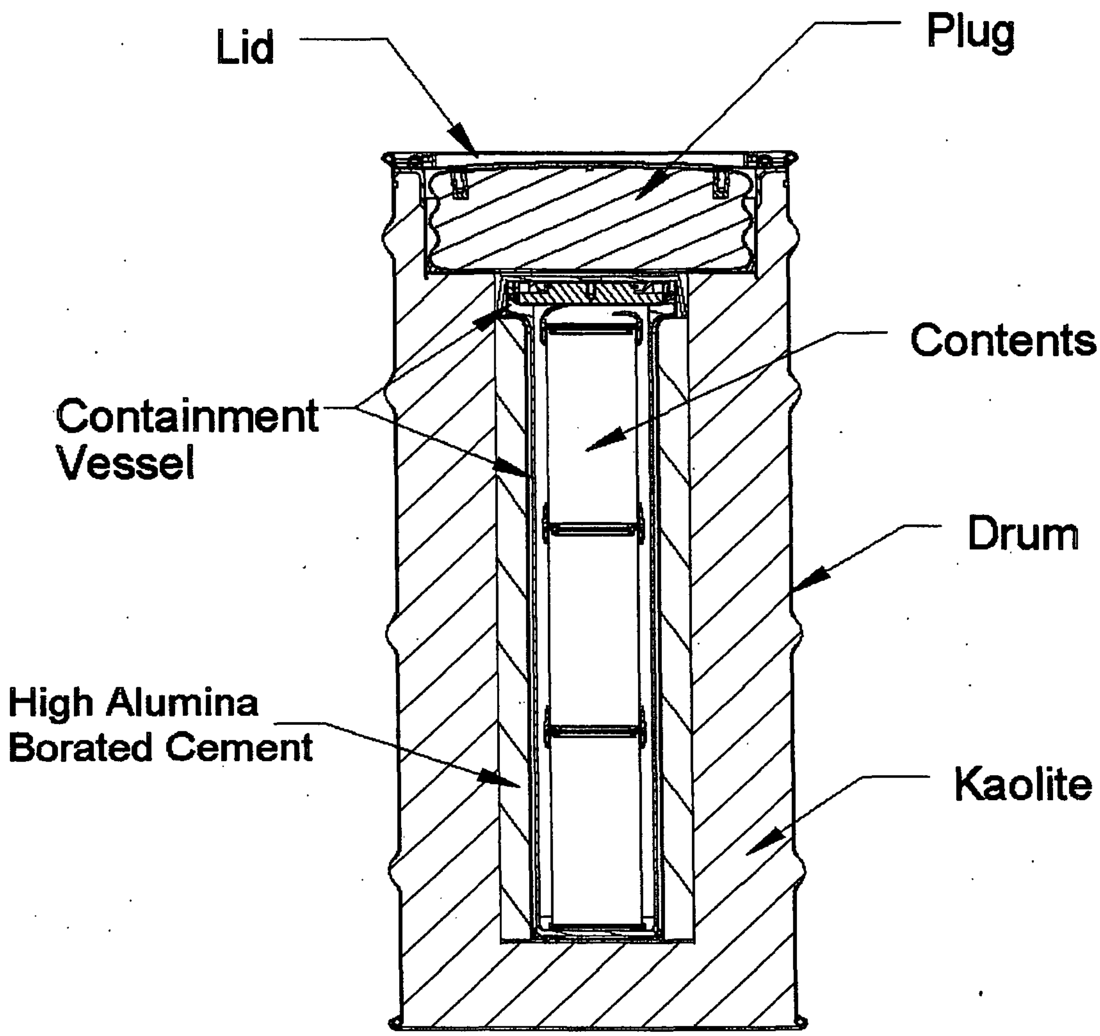


Figure 1.2 - Configuration of the Redesigned ES-3100 with the HABC as the Neutron Absorber, Presented in Part B

The Part A and Part B impact simulations were modeled with the pre-processor software TrueGrid (reference 5.1), solved with the software LS-Dyna (reference 5.2), and results obtained with the post-processor LS-Post (reference 5.3). The computers used for these simulations were Dell dual processor machines (Y12 machines ep0134, ep0141 and ep0142). TrueGrid was run on a Silicon Graphics Workstation (Y12 machine ew204). Typical solution times for one impact ranged from 1 to 4 days.

The impact simulations of the ES3100 package are driven by the 10CFR71, subpart F, sections 71.71 and 71.73 impact requirements. LS-Dyna allows successive restarts to be made which enables cumulative damage to be obtained in the shipping package model. Part A, Section 2.1, describes the specific impact simulations performed for the initial borobond design. Part B, Section 6.1, describes the simulations performed for the HABC design. Sections 3.12 and 7.7 compare the respective model results to physical test results.