BWXT Y-12

Protecting America's Future

May 8, 2006 CCN200651819

Attn: Document Control Desk
Director, Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Amendment #1 for the Model ES-3100 Shipping Container, Docket No. 71-9315, USA/9315/B(U)F-96

On behalf of the licensee of the ES-3100 shipping package, BWXT Y-12 respectfully requests an amendment to the Certificate of Compliance (CoC), Revision 0, of the ES-3100 shipping container. The purpose of this amendment is to request the addition of two specific content convenience containers for highly enriched uranium oxide contents to Section 5.(b)(2) of the CoC.

The convenience containers in this request are a polyethylene bottle and a nickel-alloy can. Polyethylene is already addressed in the Safety Analysis Report in terms of a mass limit of 500 grams inside the ES-3100 containment vessel. The use of this polyethylene bottle will be governed by that limit for total polyethylene in the package. The proposed nickel-alloy convenience can is similar to the stainless steel alloy that comprises the ES-3100 containment vessel walls. Thus, the two metals will not exhibit galvanic reactions.

The use of these convenience containers is important to the Naval Reactor program in that some of their enriched uranium oxides are processed for shipping in these containers. Naval Reactors can not procure and implement the ES-3100 system until these containers are authorized for use and specified in the CoC. Since a delay in authorization will cause Naval Reactors to delay procurement of the containers and then possibly be forced to discontinue shipping on January 1, 2007, it is hereby requested that this license amendment be expedited to the extent practical. January 1, 2007 is the date the Department of Transportation 6M specification containers can no longer be used in Department of Energy secure transporters.

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to M. DeBose

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This letter has three attachments. Attachment 1 provides the justification for this request. Attachment 2 is a suggested mark-up of the CoC. Attachment 3 contains the change pages to the Safety Analysis Report that reflect the analyses and word changes supporting the amendment (changes are highlighted). For the convenience of the reviewers, ten copies of the attachments are included.

If you have any questions regarding this submittal, please contact me at (865) 241-3854 or Jeff Arbital at (865) 576-8254.

Sincerely yours,

George B. Singleton

George B. Singleton
HEU Disposition Program Manager

GBS:slc

Attachments: As stated

cc: R. M. George, DOE, NA-261
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Docket No. 71-9315

ATTACHMENT 1

JUSTIFICATION FOR AMENDMENT 1 REQUEST
ES-3100 SHIPPING CONTAINER

ADDING 2 CONVENIENCE CONTAINERS TO THE CoC

HEU Oxide Contents in Polyethylene Bottles

The ES-3100 Safety Analysis Report (SAR) analyzed up to 500 g of "off-gassing" packing material in the containment vessel (CV) (SAR Section 1.2.3.8 (8)). This type of material included polyethylene bags, silicone rubber, and any other material that is subject to off-gassing at elevated temperatures. The licensee now wants to add polyethylene bottles as an authorized convenience container for HEU oxide contents. These bottles would fall under the existing 500 g limit already in the SAR and CoC.

The 500 g limit is not an issue, but since the diameter of the polyethylene bottles is greater than the metal cans in the SAR (and thus the void volume in the CV will be less), calculations were needed to evaluate the resultant internal pressure when the bottles are used. The calculations can be found in SAR Appendices 3.6.4 and 3.6.5. The calculations in these appendices show that the pressures internal to the CV, resulting from off-gassing of polyethylene bags and bottles, and silicone rubber at elevated temperatures (under normal and accident conditions), are well below the code allowable pressures.

The internal pressure calculations have been revised using the actual diameter of the polyethylene bottle of 4.94 inches. The resulting smaller void volume in the CV did not cause the internal pressure to increase more than a few percent (over using the smaller diameter metal cans), and still well below the code allowables.

Many minor changes to the SAR were required to add the polyethylene bottle as an authorized content convenience container.

HEU Oxide Contents in Nickel-Alloy Convenience Cans

The nickel cans are fabricated from a high nickel, deep drawable alloy, such as 200, 201, or 233. The cans have a diameter of 3 inches and height of 4.75 inches. The can is closed with a screw-type cap with an O-ring gasket. The O-ring is Parker # 2-231 Buna-N rubber (compound N1013-70). The surface of the nickel can is passivated.

The ES-3100 containment vessel is fabricated from 304L stainless steel (passivated). Passivated nickel and passivated 304L stainless steel do not have a strong effect on each other, according to the galvanic corrosion data shown below. The galvanic corrosion chart is provided by Metal Mart International, Inc. The two metals are highlighted on the chart, and their proximity to one another on the chart indicates no strong effect on one another. Thus, these two metals are compatible and the nickel-alloy can inside the CV will not cause any adverse galvanic reactions.

Several changes to the SAR were required to add the nickel-alloy can as an authorized content convenience container.

Galvanic Interaction Data

Magnesium	Anodic	Galvanic corrosion potential is a measure of how dissimilar metals will corrode when placed against each other in an assembly. Metals close to one another on the chart generally do not have a strong effect on one another, but the farther apart any two metals are separated, the stronger the corroding effect on the one higher in the list. This list represents the potential available to promote a corrosive reaction, however the actual corrosion in each application is difficult to predict. Typically, the presence of an electrolyte (eg. water) is necessary to promote galvanic corrosion. Please see chart below.
Magnesium Alloys	(least noble)	
Zinc	Corroded	
Beryllium		
Aluminum 1100, 3003, 3004, 5052, 6053		
Cadmium		
Aluminum 2017, 2024, 2117		
Mild Steel 1018, Wrought Iron		
HSLA Steel, Cast Iron		
Chrome Iron (active)		
430 Stainless (active)		
302, 303, 321, 347, 410, 416 Stainless Steel(active)		
Ni-Resist		
316, 317 Stainless (active)		
Carpenter 20Cb-3 Stainless (active)		
Aluminum Bronze (CA687)		
Hastelloy C(active) Inconel 625(active) Titanium(active)		
Lead/Tin Solder		
Lead		

Tin		
Inconel 600 (active)		
Nickel (active)		
60% Ni 15% Cr (active)		
80% Ni 20% Cr (active)		
Hastelloy B (active)		
Naval Brass (CA464), Yellow Brass (CA268)	Direction	
Red Brass (CA230), Admiralty Brass (CA443)	of attack	
Copper (CA102)		
Manganese Bronze(CA675), Tin Bronze(CA903, 905)		
410, 416 Stainless(passive) Phosphor Bronze(CA521, 524)		
Silicon Bronze (CA651, 655)		
Nickel Silver (CA 732, 735, 745, 752, 754, 757, 765, 770, 794		
Cupro Nickel 90-10		
Cupro Nickel 80-20		
430 Stainless (passive)		
Cupro Nickel 70-30		
Nickel Aluminum Bronze (CA630, 632)		
Monel 400, K500		
Silver Solder		
Nickel (passive)		
60% Ni 15% Cr (passive)		
Iconel 600 (passive)		
80% Ni 20% Cr (passive)		
Chrome Iron (passive)		
302, 303, 304, 321, 347 Stainless (passive)		
316, 317 Stainless (passive)		
Carpenter 20Cb-3 Stainless (passive), Incoloy 825 (passive)		
Silver		
Titanium (passive), Hastelloy C & C276 (passive)		
Graphite		
Zirconium	Cathodic	
Gold	(most noble)	
Platinum	Protected	

ATTACHMENT 2

SUGGESTED CHANGES IN USA/9315/B(U)F-96

[2 pages]

5.(a) Packaging (continued)

(3) Drawings

The Model No. ES-3100 package is constructed and assembled in accordance with:

(i) BWXT Y-12, L.L.C., Drawing No. M2E801580A037, Sheets 1 through 6, Rev. A, "Consolidated Assembly Drawing."

(ii) BWXT Y-12, L.L.C., Drawing No. M2E801580A026, Rev. C, "Heavy Can Spacer Assembly."

(iii) Equipment Specification JS-YMN3-801580-A001, Rev. E, "ES-3100 Containment Vessel."

(iv) Equipment Specification JS-YMN3-801580-A002, Rev. D, "ES-3100 Drum Assembly."

(v) Equipment Specification JS-YMN3-801580-A003, Rev. B, "Manufacturing Process Specification for Casting Kaolite 1600™ into the ES-3100 Shipping Package."

(vi) Equipment Specification JS-YMN3-801580-A005, Rev. C, "Casting Catalog No. 277-4 Neutron Absorber for the ES-3100 Shipping Package."

5.(b) Contents (Type and form of material, maximum quantity of material per package, and Criticality Safety Index (CSI)).

The weight of the radioactive contents, convenience ~~cans,~~ containers can lift attachments, polyethylene bags, spacers, and other material in the containment vessel shall not exceed 90 lb. The maximum mass of hydrogenous packaging materials in the containment vessel (e.g., polyethylene containers or bagging, silicone rubber pads, etc.) shall not exceed 500 grams. The maximum content decay heat load shall not exceed 0.4 watts. ✓

The concentration limits of uranium and transuranic constituents shall be the following:

Isotope	Maximum Concentration
U-232	0.040 μg/gU[a]
U-233	0.006 g/gU[b]
U-234	0.02 g/gU
U-235	1.00 g/gU
U-236	0.40 g/gU
Transuranics (except Np)	40.0 μg/gU
Np-237	0.003 g/gU

[a] μg/gU = 10^{-6} grams per gram of total uranium
[b] g/gU = grams per gram of total uranium

5.(b)(1) Contents (continued)

Table 2: Loading Limits for Solid Metal or Alloy in the Form Defined as Broken Metal (Continued)

Uranium Enrichment (weight percent U-235)	CSI	With Spacers Maximum Mass U-235 (kg)[a]		No Spacers Maximum Mass U-235 Per Package (kg)[a]
		Per Convenience Can	Per Package	
> 60 and ≤ 70	0.0	1.949	5.848	1.949
	0.4	4.115	12.346	7.797
	0.8	6.931	20.793	16.245
	2.0	8.231	24.692	24.692
≤ 60	0.0	3.718 kgU	11.153 kgU	5.576 kgU
	0.4	9.914 kgU	29.743 kgU	17.660 kgU
	0.8	11.773 kgU	35.320 kgU	35.320 kgU
	2.0	11.773 kgU	35.320 kgU	35.320 kgU

[a] All limits are expressed in kg U-235 unless specified as kgU, which means kilograms of total uranium.

(2) Uranium as oxide, which may include UO_2, UO_3, and U_3O_8, packaged in stainless-steel, ~~or~~ tin-plated carbon steel, ~~convenience cans~~ or nickel-alloy convenience cans, or polyethylene bottles. The physical form of all contents is dense, loose powder which may contain clumps and pellets. Moisture content in oxide is limited to 3 weight percent water. The mass limit shall be 24.0 kg of oxide, with a maximum mass of 21.124 kg U-235, with a CSI of 0.0. No spacers are required in the containment vessel. ✓

(3) Solid uranyl nitrate in the form of uranyl nitrate crystals, $[UO_2(NO_3)_2 \cdot xH_2O$, where x is ≤ 6]. Uranyl nitrate crystals must be contained in a non-metallic convenience container (such as Teflon or polyethylene bottle). The mass limit shall be 24.0 kg of uranyl nitrate crystals, with a maximum mass of 11.303 kg U-235, with a CSI of 0.0. No spacers are required in the containment vessel.

6. The vent holes on the outer steel drum shall be capped closed during transport and storage to preclude entry of rain water into the insulation cavity of the drum.

7. Content forms may not be mixed in a single ES-3100 containment vessel.

ATTACHMENT 3

CHANGE PAGES FOR THE ES-3100 SAFETY ANALYSIS REPORT

[Y/LF-717, Rev 0]

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 ⅜-16 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, and uranyl nitrate crystals (UNX). The ES-3100 package has been designed to accommodate a maximum of 24 kg of oxide or UNH crystals and a maximum of 36 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 Np) may be present in the contents at a maximum concentration of 40.0 μg/gU. The concentration of Np is limited to 0.003 g/gU.

HEU Oxide

The HEU oxide content in the ES-3100 package includes UO_2, UO_3, and U_3O_8. Six different oxide categories have been identified (Appendix 1.4.7). Maximum overall uranium isotopic weight percents representative of all six 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 3 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 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 six oxide categories are referred to as Groups 1-6. These six 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).

The oxides in Groups 1, 3, and 4 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.

<u>HEU Metal and Alloy</u>

HEU metal and alloy may be in the form of solid geometric shapes. Solid shapes may include the following:

1. spheres having a diameter no larger than 3.24 in. (maximum of two spheres per convenience can);

2. cylinders having a diameter no larger than 3.24 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).

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.

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 shipped in the ES-3100 must meet the following restrictions:

1. Pyrophoric forms, such as uranium metal powders, foils, turnings and wires shall not be shipped, unless the materials pass the following broken metal size restriction tests. Broken metal pieces should be of a size that: a) the specific surface area does not exceed 50 cm^2/g, and b) will not pass freely through a mesh size 8 sieve (2.38 mm or 0.0937 in). Other tests to determine pyrophoricity of the uranium metal contents may be used at the shipper's discretion and are subject to approval by the regulatory authority.

2. Incidental small particles and samples (those which do not pass the size restriction tests in #1) including foils, turnings, or wires may be shipped with the original batch, but are restricted to < 1% by weight of the content batch.

Metal 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. ~~These types of convenience containers are not covered in this SAR.~~

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 the ES-3100 package with bulk HEU content, the maximum number of A_2s is 290.37 (at 70 years) and the maximum activity is 0.3112 Tbq (at 10 years) [Table 4.4].

1.2.3.2 Chemical and physical form

The fissile material contents are in solid (HEU metal or alloy), crystalline (UNX) or powder (HEU oxide) form. Some moisture (up to 3%) 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 Cat 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

Table 1.3. Authorized content [a] and fissile mass loading limits [b,c] for the ES-3100

Content description		Enrichment	CSI	No spacers, ^{235}U (kg)	Cat 277-4 can spacers,[d] ^{235}U (kg)
Solid HEU metal or alloy (specified geometric shapes)[e]	Spheres	≤ 100%	0.0	16.946	32.983
	Cylinders	≤ 100%	0.0	12.000	18.000
	Square bars	≤ 100%	0.0	18.000	30.000
	Slugs	> 80%	0.0	Can spacers req'd [d]	16.342
	Slugs	≤ 80%	0.0	Can spacers req'd	26.213
Broken HEU metal or alloy		> 95%, ≤ 100%	0.0	Can spacers req'd	2.774
			0.4	Can spacers req'd	5.548
			0.8	Can spacers req'd	8.323
			2.0	Can spacers req'd	11.097
		> 90%, ≤ 95%	0.0	Can spacers req'd	2.637
			0.4	Can spacers req'd	5.274
			0.8	Can spacers req'd	10.549
			2.0	Can spacers req'd	16.703
		> 80%, ≤ 90%	0.0	Can spacers req'd	2.500
			0.4	Can spacers req'd	7.500
			0.8	Can spacers req'd	10.000
			2.0	Can spacers req'd	15.834
		> 70%, ≤ 80%	0.0	2.225	2.225
			0.4	4.450	8.900
			0.8	14.092	18.542
			2.0	18.542	23.734
		> 60%, ≤ 70%	0.0	1.949	5.848
			0.4	7.797	12.346
			0.8	16.245	20.793
			2.0	24.692	24.692
		≤ 60%	0.0	5.576 kgU	11.153 kgU
			0.4	17.660 kgU	29.743 kgU
			0.8	35.320 kgU	35.320 kgU
			2.0	35.320 kgU	35.320 kgU
HEU oxide		> 20%, ≤ 100%	0.0	21.124 [f]	Spacer not req'd
UNX crystals [a,g]		> 20%, ≤ 100%	0.0	11.303 [f]	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] Cat 277-4 can spacers as described on Drawing No. M2E801580A026 (Appendix 1.4.8).
[e] Geometries of solid shapes are as follows:
- Spheres are no larger than 3.24 in. diameter: maximum of 2 spheres per can.
- Cylinders are 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).

evaluation (Sect. 6). In addition to the materials of construction in the ES-3100 shipping package mentioned above, the Cat 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).

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 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 Cat 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.

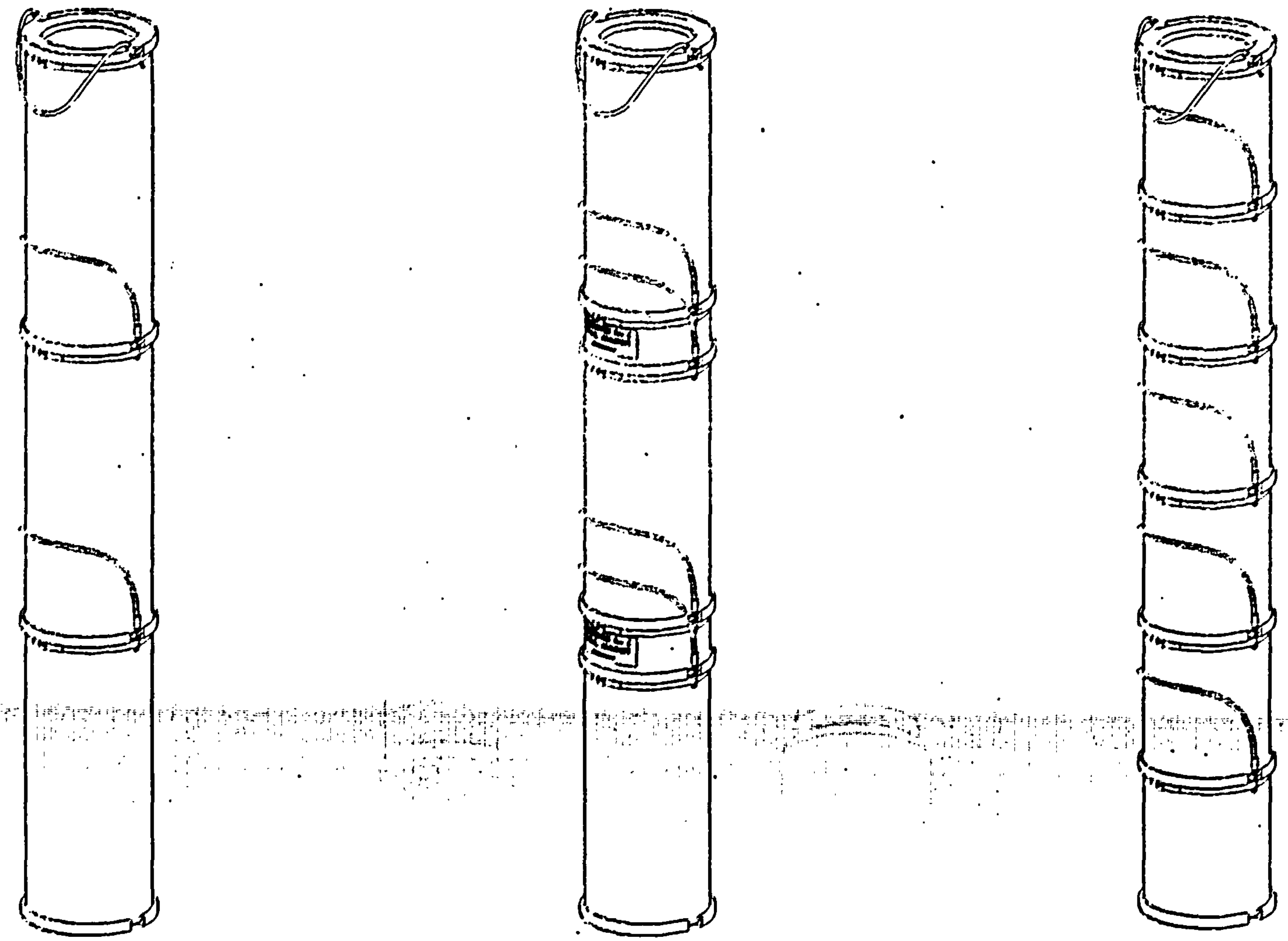
Typical configurations of authorized ES-3100 convenience containers are shown in Fig. 1.4. The shipping configurations shown in Fig. 1.4 utilize 3.00 and 4.25-in.-diameter convenience cans of various heights (4.75, 4.88, 8.75, and 10 in.), and 4.94 in. diameter by 8.7 in. tall polyethylene bottles. Although any combination of the convenience cans that will fit inside the internal volume of the containment vessel may be used, although content forms will not be mixed in a single package (i.e., HEU oxides may not be shipped 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 (see Sect. 1.2.3.8 for mass limits on packing materials such as polyethylene bagging). 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 maximum gross shipping weight of the ES-3100 package with any proposed content is 187.81 kg (414.05 lb)

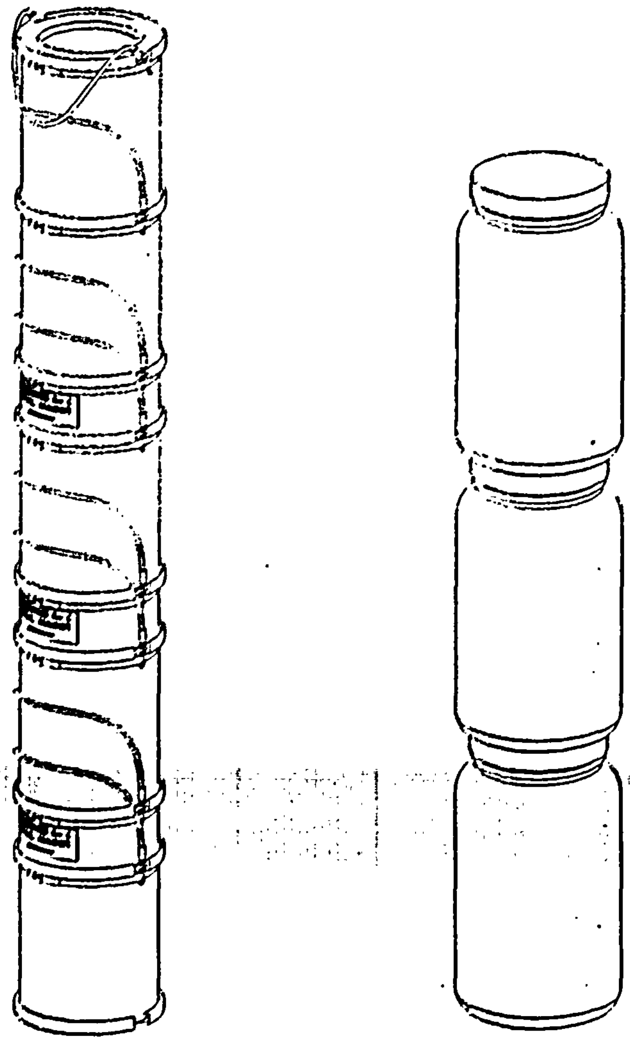


Three Cans
ø4.25" × 10" Tall
[redacted]

Three Cans
ø4.25" × 8.75" Tall
and Two Spacers

Six Cans
ø4.25" × 4.88" Tall or
[redacted]

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



Five Cans
⌀4.25" × 4.88" Tall
and four spacers

Three Poly Bottles
⌀4.94" × 8.7" Tall

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

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[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 in the ES-3100 shipping package is limited to 36 kg (79.37 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, polyethylene bags, can spacers, etc.), is 40.82 kg (90 lb). 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). 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.

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, or polyethylene 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 loading is further restricted to piece sizes with a specific area not greater than 50 cm^2/g and not smaller than sieve mesh size 8 (2.38 mm or 0.0937 in). Incidental small particles and samples (those which do not pass the size restriction tests) including foils, turnings, or wires may be shipped with the original batch, but are restricted to < 1% by weight of the content batch.

(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 between any two 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 that off-gas (i.e., polyethylene bottles, polyethylene bagging, silicone rubber, etc.) used inside the ES-3100 containment vessel is limited to 500 g (Sect. 3.1.4.2).

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 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 seal is only required when HEU is in the package. It is not required for empty shipments.

2. STRUCTURAL EVALUATION

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

As described in the following sections, design analysis, similarity, drop simulations, and the full-scale testing documented herein demonstrates that the ES-3100 package is in compliance with the requirements of Title 10 Code of Federal Regulations (CFR) 71 and Title 49 CFR 100–178 when it is used to ship contents described above. The maximum bounding activity of the contents (36 kg of HEU) is 3.1017×10^{-1} TBq (8.38 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 290.37. This information is further discussed in Sect. 4.

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

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

2.1 DESCRIPTION OF STRUCTURAL DESIGN

2.1.1 Discussion

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

2.1.1.1 Drum assembly

The drum assembly of the shipping package is defined as the structure that maintains the position of and provides protection to the impact and thermal barrier surrounding the containment boundary. Preserving the location of the containment boundary within the packaging prevents reduction of the shielding and subcriticality effectiveness. The drum assembly for the ES-3100 consists of an internally flanged Type 304L stainless-steel 30-gal modified drum with two type 304L stainless-steel inner liners, one filled with noncombustible cast refractory insulation and impact limiter (Kaolite) and one filled with noncombustible cast neutron absorber (Cat 277-4), a stainless-steel top plug with cast refractory insulation, silicone rubber pads, silicon bronze hex-head nuts, and a stainless-steel lid and bottom (Drawing M2E801580A031, Appendix 1.4.8). 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. The cans shall have a diameter of ≤12.7 cm (5 in.) and heights of ≤25.4 cm (10 in.). Any combination of these cans shall be allowed in a single package, as long as the total length of the can stack (with spacers and pads as required) does not exceed the inside working height of the containment vessel (31 in.). 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. Any closure on the convenience can is allowed. 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 3.12 cm (1.23 in.) in height and weigh ~0.47 kg (1.03 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 97.63 kPa (14.16 psi) and 239.22 kPa (34.70 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 3.112×10^{-1} TBq (8.41 Ci) at 10 years from initial fabrication; the maximum number of A_2s carried is 290.26 at 50 years following initial fabrication (Table 4.4). Based on the guidance from Regulatory Guide 7.11, *Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)*, this package is classified in NUREG-1609 (Table 1.1) as a Category II shipping package. However, since the ES-3100 may be used for future contents that exceed 3000 A_2 (under a different SAR and certificate), this package has been classified as a Category I shipping package. Therefore, the containment vessel is designed (using nominal dimensions for each component), fabricated, and inspected in accordance with the American Society of Mechanical Engineers (ASME) *Boiler and Pressure Vessel Code*, Sect. III, Division I, Subsection NB. The design and subsequent verification comply with the requirements of 10 CFR 71. The structural requirements for the packaging under NCT are addressed in Sect. 2.6. The structural requirements for the packaging under HAC are addressed in Sect. 2.7.

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 kg/m³ (22.4 lb/ft³) density, cast in stainless-steel shells in the drum and top plug
Neutron absorber	Cat 277-4, 1681.9 ±80.1kg/m³ (105 ±5 lb/ft³) 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
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

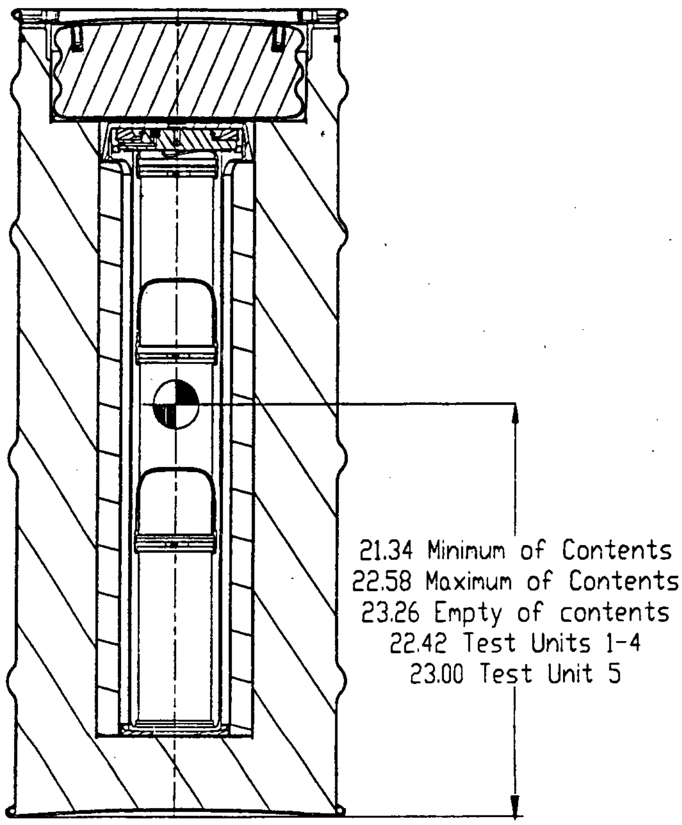
2.1.3 Weights and Centers of Gravity

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 Three 8.75" tall can configuration kg (lb)	ES-3100 Three 8.7" tall polyethylene 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)	121.96 (268.87)	121.96 (268.87)	121.96 (268.87)	[redacted]	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)	[redacted]	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)	[redacted]	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)**	[redacted]	**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)	[redacted]	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)	[redacted]	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)**	[redacted]	**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)	[redacted]	0.0 (0.00)	--
Silicone vibration pads	0.11 (0.23)	0.18 (0.41)	0.24 (0.522)	0.16 (0.35)	[redacted]	0.0 (0.00)	--
Spacers with handles	0	0	2.07 (4.56)	1.38 (3.04)	[redacted]	0.0 (0.00)	--
Polyethylene bagging	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	0.5 (1.10)	[redacted]	0.0 (0.00)	--
Metal scouring pads	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.14 (0.30)	[redacted]	0.0 (0.00)	--
HEU content	36.0 (79.37)	36.0 (79.37)	36.0 (79.37)	36.0 (79.37)	[redacted]	0.0 (0.00)	--
Total proposed content weight	**37.32 (82.29)**	**37.69 (83.10)**	**39.64 (87.40)**	**38.65 (85.21)**	[redacted]	**0**	**40.82 (90)**
Total shipping package weight	**184.31 (406.34)**	**184.68 (407.15)**	**186.63 (411.45)**	**185.64 (409.26)**	[redacted]	**146.88 (323.79)**	**187.81 (414.05)**

[a] Calculated weight using Pro/ENGINEER software with nominal dimensions and densities (Pro/ENGINEER Version 20).

Table 2.10. Calculated center of gravity for the various ES-3100 shipping arrangements (cont.)

Content description	Distance from drum's bottom (in.)
BARS - 36,000 g (79.366 lb) max - no can spacers	
3 full 8.75" high cans	22.134
2 full 8.75" cans + 1 empty 8.75" high can	21.836
1 full 8.75" high can + 2 empty 8.75" high cans	22.151
3 full 10" high cans	22.386
2 full 10" high cans + 1 empty 10" high can	21.932
1 full 10" high can + 2 empty 10" high cans	22.160
4 full 4.88" high cans + 1 partially full 10" high can	21.953
4 full 4.88" high cans + 1 empty 10" high can	21.808
3 full 4.88" high cans + 1 empty 4.88" high can + 1 empty 10" high can	21.781
2 full 4.88" high cans + 2 empty 4.88" high cans + 1 empty 10" high can	21.989
1 full 4.88" high can + 3 empty 4.88" high cans + 1 empty 10" high can	22.457
SLUGS - 31,070 g (68.498 lb) max - with can spacers	
3 full 4.88" high cans + 1 empty 10" high can + 3 can spacers	21.420
2 full 4.88" high cans + 1 empty 4.88" high can + 1 empty 10" high can + 3 can spacers	21.524
1 full 4.88" high can + 2 empty 4.88" high cans + 1 empty 10" high can + 3 can spacers	22.076
3 full 4.88" high cans + 2 empty 4.88" high cans + 4 can spacers	21.444
2 full 4.88" high cans + 3 empty 4.88" high cans + 4 can spacers	21.549
1 full 4.88" high cans + 4 empty 4.88" high cans + 4 can spacers	22.100
3 full 8.75" high cans + 2 can spacers	22.088
2 full 8.75" high cans + 1 empty 8.75" high can + 2 can spacers	21.808
1 full 8.75" high can + 2 empty 8.75" high cans + 2 can spacers	22.117
OXIDE - 24,000 g (52.910 lb) max - with no spacers	
3 full 8.7" high polyethylene bottles + bagging	22.369
2 full 8.7" high polyethylene bottles + 1 empty 8.7" high polyethylene bottle + bagging	22.207
1 full 8.7" high polyethylene bottle + 2 empty 8.7" high polyethylene bottles + bagging	22.477

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 2.17. 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/cm^3 (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 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 bottles will 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. 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 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, HEU loading is further restricted to metal piece sizes with a specific area not greater than 50 cm^2/g and not smaller than sieve mesh size 8 (2.38 mm or 0.0937 in). Incidental small particles and samples (those which do not pass the size restriction tests) including foils, turnings, or wires may be shipped with the original batch, but are restricted to < 1% by weight of the content batch.

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.

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 122.63 kPa (17.786 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 122.63 kPa (17.786 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 or polyethylene 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 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).

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 340.57 kPa (49.396 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 @239.22 kPa (34.70 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)	2.357×10^3 (341.9)	55.2	1.478×10^3 (214.4)	88.6	1.324×10^5 (19,200)[b]
Closure nut ring (away from threaded portion)	5.948×10^4 (8627.1)	6.7	4.246×10^4 [f] (6158)	9.8	4.571×10^5 (66,300)[c]
Top flat head (sealing surface region)	2.122×10^4 (3078.0)	11.5	1.665×10^4 [f] (2415)	14.9	2.648×10^5 (38,400)[c]
Cylindrical section (middle)	6.833×10^3 (991.0)	11.9	4.285×10^3 (621.5)	19.6	8.825×10^4 (12,800)[d]
Cylindrical section (shell-to-flange interface)	1.547×10^4 (2243.4)	16.1	1.238×10^4 (1795.3)	20.4	2.648×10^5 (38,400)[c]
Cylindrical section (shell-to-bottom interface)	1.753×10^4 (2541.9)	14.1	1.099×10^4 (1594.2)	23.1	2.648×10^5 (38,400)[c]
Body flange threads load, kg (lb)	1.298×10^3 (2861.8)	14.8	9.072×10^2 [f] (2000)	21.6	2.053×10^4 (45266)[e]
Body flange thread region (under cut region)	3.685×10^4 (5344.1)	6.2	2.397×10^4 [f] (3476)	10	2.648×10^5 (38,400)[c]
Flat bottom head (center)	1.650×10^4 (2392.8)	7.0	1.035×10^4 (1500.7)	11.8	1.324×10^5 (19,200)[b]
Closure nut thread load, kg (lb)	1.298×10^3 (2861.8)	26.3	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 ~290.26. 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.);

3.1.3.2 HAC Temperature Summary Tables

In order to predict the maximum temperature for the packaging components during HAC, a transient thermal analyses was performed on the finite element model of the ES-3100 shipping container (undamaged configuration) to simulate HAC as prescribed by 10 CFR 71.73(c)(4). A 30-min fire of 800°C (1475°F) was simulated by applying natural convection and radiant exchange boundary conditions to all external surfaces of the drum (assuming the drum is in a horizontal orientation) with content heat loads of 0, 0.4, 20, and 30 W. There are no heat flux boundary conditions simulating insolation applied to the model before and during the 30-minute fire. The initial temperature distribution within the package having content heat loads of 0.4, 20, and 30 W is obtained from their respective steady-state analyses (Table 3.5). The initial temperature distribution within the package having no content heat load (0 W) is assumed to be at a uniform temperature equal to the ambient temperature of 38°C (100°F). The content heat load is simulated by applying a uniform heat flux to the internal surfaces of the elements representing the containment vessel.

Following the 30-min fire transient analyses, 48-h cool-down transient thermal analyses are performed using the temperature distribution at the end of the fire as the initial temperature distribution. During post-fire cool-down, natural convection and radiant exchange boundary conditions are applied to all external surfaces of the drum (assuming the drum is in a horizontal orientation). Additionally, cases are analyzed in which insolation is included during the post-fire cool-down. For the cases in which insolation is applied to the model during cool-down, insolation is applied during the first 12-h period following the 30-min fire, and then alternated (off, then on) as was done for NCT.

Based on the previous analysis of the ES-3100 package using BoroBond4 (Appendix 3.6.1), it was noted that using the low-end density of Kaolite 1600 results in higher containment vessel temperatures than using the high-end density of Kaolite 1600. For this reason, the NCT and HAC thermal analyses were run using a density of 19.4 lb/ft^3. Similarly, the low-end density of the Cat 277-4 material (100 lb/ft^3) was also used in these analyses. However, while using these low-end densities will result in higher temperatures to the containment vessel, using the high-end densities for these two materials will result in higher temperature differences from the baseline case. Thus, HAC runs are also made for heat loads of 0, 0.4, 20, and 30 W using a Kaolite 1600 density of 30 lb/ft^3 and a Cat 277-4 density of 110 lb/ft^3.

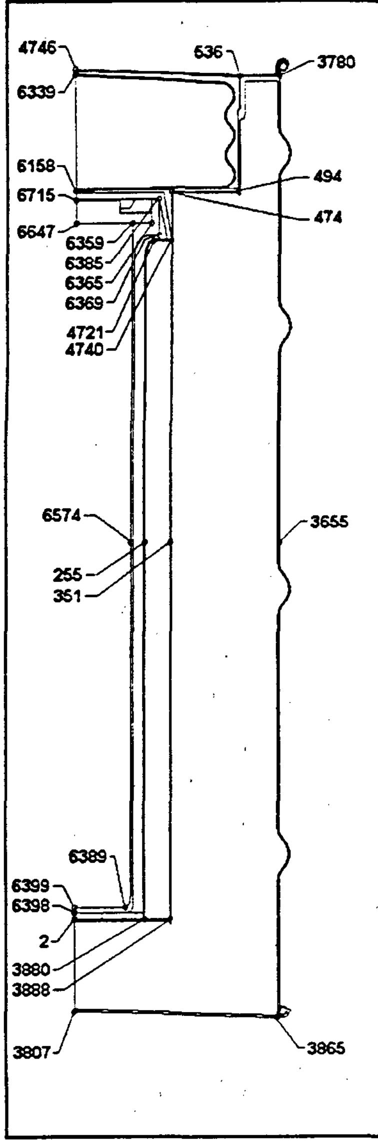
The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.7 for the analyses using a Kaolite 1600 density of 19.4 lb/ft^3 and a Cat 277-4 density of 100 lb/ft^3. The maximum temperatures calculated for the ES-3100 shipping container for HAC are summarized in Table 3.8 for the analyses using a Kaolite 1600 density of 30 lb/ft^3 and a Cat 277-4 density of 110 lb/ft^3. The thermal analyses that use the low-end density values for Kaolite 1600 and Cat 277-4 achieve the higher package temperatures (see Table 3.7).

3.1.4 Summary Tables of Maximum Pressures

3.1.4.1 Maximum NCT Pressures

Table 3.10 summarizes the results from Appendix 3.6.4 in which the pressure of the containment vessel when subjected to the tests and conditions of NCT per 10 CFR 71.71 has been determined for the most restrictive containment vessel arrangements (CVAs) shipped in the ES-3100. The most restrictive CVAs are those in which the void volume inside the containment vessel is minimized based on content volumes and those CVAs that carry the largest mass of items that off-gas at the predicted temperatures during NCT. Several convenience container heights are proposed for shipment (Fig. 1.4). Shipping configurations will use these containers in any configuration as long as it does not exceed the HEU weight limit and form and does not exceed the height constraint of the containment vessel. However, in order to determine the worst-case

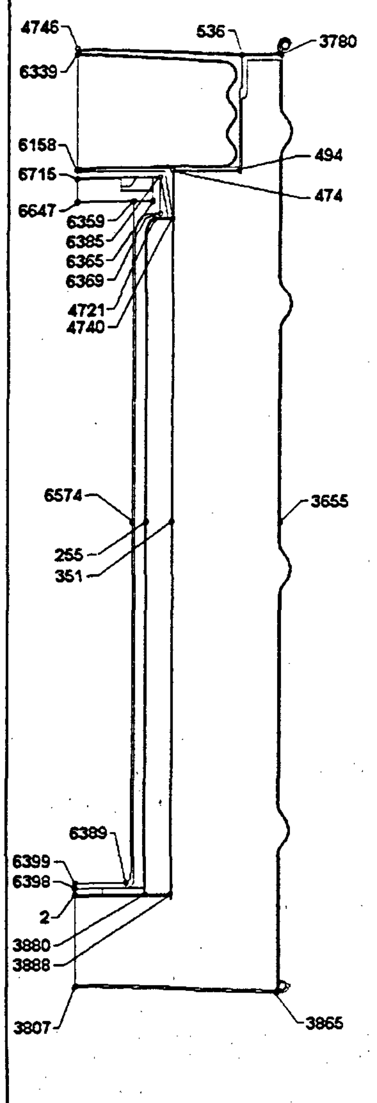
Table 3.7. ES-3100 shipping container HAC maximum temperatures (Kaolite 1600 density of 19.4 lb/ft^3 and Cat 277-4 density of 100 lb/ft^3)

Node map	Node coordinates (in.)			HAC maximum temperature (°F)							
	No.	r	z	0 W		0.4 W		20 W		30 W	
				Insolation during cool-down?		Insolation during cool-down?		Insolation during cool-down?		Insolation during cool-down?	
				No[b]	Yes	No	Yes	No	Yes	No	Yes
	2	0.000	4.505	225.5	232.1	226.2	232.8	255.5	261.7	269.5	275.7
	255	3.180	21.528	194.5	212.5	195.2	213.2	223.8	241.3	237.8	255.3
	351	4.300	21.528	195.8	211.9	196.4	212.5	222.3	237.8	234.8	250.3
	474	4.300	37.535	392.9	395.0	393.2	395.4	407.6	409.7	414.2	416.3
	494	7.325	37.525	671.2	672.0	671.4	672.3	679.1	680.0	682.5	683.3
	536	7.385	42.755	1380.4	1380.4	1380.4	1380.4	1380.9	1380.9	1381.1	1381.1
	3655	9.185	21.528	1457.8	1457.8	1457.8	1457.8	1458.0	1458.0	1458.1	1458.1
	3780	9.185	42.755	1427.8	1427.8	1427.9	1427.9	1428.1	1428.1	1428.2	1428.2
	3807	0.000	0.320	1454.5	1454.5	1454.5	1454.5	1454.9	1454.9	1455.0	1455.0
	3865	9.185	0.008	1470.1	1470.1	1470.1	1470.1	1470.1	1470.1	1470.2	1470.2
	3880	3.178	4.505	230.6	236.4	231.2	237.0	257.1	262.5	269.4	274.8
	3888	4.300	4.505	236.9	241.7	237.5	242.3	261.5	266.1	272.9	277.5
	4721	3.500	35.275	245.7	252.8	246.2	253.3	266.8	273.8	276.6	283.6
	4740	4.300	35.275	258.4	263.5	258.8	264.0	278.1	283.1	287.1	292.1
	4746	0.000	43.065	1448.0	1448.0	1448.0	1448.0	1448.2	1448.2	1448.3	1448.3
	6158	0.000	37.579	308.7	311.6	309.1	312.0	328.3	331.2	337.3	340.2
	6339	0.000	42.859	1335.1	1335.1	1335.2	1335.2	1336.4	1336.4	1336.9	1336.9
	6359[a]	2.530	36.075	236.7	247.6	237.3	248.3	266.2	276.6	279.8	289.9
	6365[a]	3.425	36.075	236.6	247.6	237.3	248.3	266.0	276.4	279.5	289.7
	6369	3.750	35.525	236.5	247.6	237.2	248.2	265.8	276.2	279.3	289.5
	6385	3.750	37.175	237.3	248.2	237.9	248.8	266.1	276.4	279.4	289.5
	6389	2.310	5.025	219.0	227.4	219.9	228.2	255.3	263.1	272.2	279.9
	6398	0.000	4.775	219.7	227.9	220.5	228.7	255.6	263.3	272.5	280.0
	6399	0.000	5.025	219.7	227.9	220.5	228.7	255.6	263.3	272.5	280.0
	6574	2.530	21.528	196.1	214.9	197.3	216.0	246.7	263.8	269.9	286.5
	6647	0.000	36.075	237.2	248.0	237.9	248.6	266.8	277.0	280.4	290.4
	6715	0.000	37.135	237.4	248.1	238.0	248.8	266.8	277.0	280.4	290.4

[a] Approximate location of the CV O-ring.
[b] Baseline case for ΔT comparisons.

Table 3.8. ES-3100 shipping container HAC maximum temperatures (Kaolite 1600 density of 30 lb/ft^3 and Cat 277-4 density of 110 lb/ft^3)

Node map



Node coordinates (in.)			HAC maximum temperature (°F)							
			0 W		0.4 W		20 W		30 W	
			Insolation during cool-down?		Insolation during cool-down?		Insolation during cool-down?		Insolation during cool-down?	
No.	r	z	No[b]	Yes	No	Yes	No	Yes	No	Yes
2	0.000	4.505	209.9	218.9	210.6	219.6	240.4	248.8	254.6	262.8
255	3.180	21.528	185.5	207.7	186.1	208.4	215.1	236.6	229.3	250.6
351	4.300	21.528	185.6	207.4	186.2	208.0	212.3	233.3	225.0	245.9
474	4.300	37.535	342.9	345.5	343.3	345.9	358.1	360.7	365.0	367.5
494	7.325	37.525	596.3	597.4	596.5	597.6	604.7	605.8	608.3	609.4
536	7.385	42.755	1366.8	1366.8	1366.8	1366.8	1367.4	1367.4	1367.6	1367.6
3655	9.185	21.528	1452.8	1452.8	1452.8	1452.8	1453.0	1453.0	1453.1	1453.1
3780	9.185	42.755	1420.8	1420.8	1420.8	1420.8	1421.0	1421.0	1421.2	1421.2
3807	0.000	0.320	1449.4	1449.4	1449.4	1449.4	1449.8	1449.8	1449.9	1449.9
3865	9.185	0.008	1467.3	1467.3	1467.3	1467.3	1467.4	1467.4	1467.4	1467.4
3880	3.178	4.505	213.1	221.4	213.7	222.0	240.0	247.9	252.5	260.3
3888	4.300	4.505	217.0	224.4	217.6	225.0	242.1	249.1	253.8	260.7
4721	3.500	35.275	228.0	237.5	228.5	238.0	249.7	259.0	259.7	269.0
4740	4.300	35.275	236.5	243.8	236.9	244.3	256.7	263.9	266.0	273.2
4746	0.000	43.065	1441.8	1441.8	1441.8	1441.8	1442.0	1442.0	1442.1	1442.1
6158	0.000	37.579	277.3	281.8	277.8	282.3	297.5	302.0	306.7	311.2
6339	0.000	42.859	1299.5	1299.5	1299.6	1299.6	1301.1	1301.1	1301.7	1301.7
6359[a]	2.530	36.075	225.1	237.3	225.8	237.9	254.7	266.1	268.3	279.6
6365[a]	3.425	36.075	225.0	237.3	225.7	237.9	254.5	266.0	268.1	279.3
6369	3.750	35.525	224.9	237.2	225.6	237.8	254.3	265.8	267.9	279.2
6385	3.750	37.175	225.5	237.6	226.2	238.3	254.6	266.1	268.0	279.2
6389	2.310	5.025	205.3	215.9	206.2	216.8	242.0	251.9	259.2	268.9
6398	0.000	4.775	205.8	216.3	206.7	217.1	242.2	252.0	259.2	268.8
6399	0.000	5.025	205.8	216.3	206.7	217.1	242.2	252.0	259.3	268.8
6574	2.530	21.528	187.8	209.1	189.0	210.2	238.9	258.4	262.4	281.3
6647	0.000	36.075	225.6	237.7	226.3	238.3	255.2	266.5	268.9	280.0
6715	0.000	37.135	225.8	237.8	226.4	238.4	255.2	266.5	268.9	280.0

[a] Approximate location of the CV O-ring.
[b] Baseline case for ΔT comparisons.

Table 3.9. 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)
Adjacent to CV body wall high	99 (210)	99 (210)	99 (210)	99 (210)	104 (219)
Adjacent to CV body wall middle	99 (210)	93 (199)	116 (241)	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 Tables 5.3 through 5.7 in ORNL/NTRC-013. Vol. 1 for recorded values.
[b] Temperature indicating patch may have been damaged due to impact with surrounding structure.

shipping configuration, the arrangements that minimize the void volume inside the containment vessel are analyzed as follows:

1. one shipment will contain six cans with external dimensions of 10.8 cm (4.25 in.) diameter by 12.38 cm (4.875 in.) high cans, or six cans with external dimensions of 7.62 cm (3.00 in.) diameter by 12.07 cm (4.75 in.).
2. one shipment will contain five cans with external dimensions of 10.8 cm (4.25 in.) diameter by 12.38 cm (4.875 in.) high cans and four can spacers;
3. one shipment will contain three cans with external dimensions of 10.8 cm (4.25 in.) diameter by 22.23 cm (8.75 in.) high and three can spacers;
4. one shipment will contain three cans with external dimensions of 10.8 cm (4.25 in.) diameter by 25.4 cm (10 in.) high; and
5. ~~one shipment will contain three cans with external dimensions of 12.70 cm (5.00 in.) diameter by 25.4 cm (10 in.) high.~~
6. one shipment will contain three polyethylene bottles with external dimensions of 12.54 cm (4.94 in.) diameter by 22.1 cm (8.7 in.) high.

These arrangements are shown in Fig. 1.4. To determine the ES-3100's maximum normal operating pressure, the following assumptions have been used in the calculations:

1. The HEU contents are loaded into convenience cans, and convenience cans are placed inside the containment vessel at standard temperature (T_{amb}) and pressure (P_t) [25°C (77°F) and 101.35 kPa (14.7 psia)] with air at a maximum relative humidity of 100%.

2. The convenience cans and bottles are assumed to be sealed to minimize the void volume inside the containment vessel.
3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel.
4. For polyethylene bottle configurations, polyethylene bottles and bagging weight is limited to 500 g per containment vessel.
5. ~~No contents that will off-gas at temperatures about ambient temperature can be used inside the containment vessel when convenience cans are greater than 10.80 cm (4.25 in.) in diameter.~~

Table 3.10. Total pressure inside the containment vessel at 87.81°C (190.06°F) [a]

CVA	n_a (lb-mole)	n_v (lb-mole)	n_{po} (lb-mole)	n_{bo} (lb-mole)	n_T (lb-mole)	P_T (psia)
1	3.0855e-04	1.0057e-05	0.0000e+00	0.0000e+00	3.1861e-04	17.786
2	3.1264e-04	1.0190e-05	0.0000e+00	0.0000e+00	3.2283e-04	17.786
3	3.1997e-04	1.0429e-05	0.0000e+00	0.0000e+00	3.3040e-04	17.786
4	2.9252e-04	9.5344e-06	0.0000e+00	0.0000e+00	3.0205e-04	17.786
5	6.7348e-05	2.1951e-06	0.0000e+00	0.0000e+00	6.9543e-05	17.786
6	2.3215e-04	7.5666e-06	0.0000e+00	0.0000e+00	2.3972e-04	61.309

[a] This assumes that the convenience cans, polyethylene bottles, and Cat 277-4 spacer cans are sealed.

3.1.4.2 Maximum HAC Pressures

Table 3.11 summarizes the results from Appendix 3.6.5 in which the pressure of the containment vessel when subjected to the tests and conditions of HAC per 10 CFR 71.73 has been determined for the most restrictive CVAs shipped in the ES-3100. The shipping configurations discussed in Sect. 3.1.4.1 are evaluated for HAC. To determine the maximum pressure generated inside the ES-3100's containment vessel due to HAC conditions, the following assumptions have been used in the calculations:

1. The initial pressure inside the containment vessel is the maximum normal operating pressure shown in Table 3.10 for each CVA at ambient temperature.
2. The convenience cans and bottles are assumed to be sealed in order to minimize the void volume inside the containment vessel.
3. Convenience can and bottle geometry does not change during pressure increase inside containment vessel or because of damage from compliance testing.
4. For polyethylene bottle configurations, polyethylene bottles and bagging weight is limited to 500 g per containment vessel.
5. ~~No contents that will off-gas at temperatures about ambient temperature can be used inside the containment vessel when convenience cans are greater than 10.80 cm (4.25 in.) in diameter.~~

The above assumptions are very conservative because the convenience cans buckle and deform significantly under an external pressure differential of one atmosphere as demonstrated during the helium leak checking. When the convenience cans deform inward under external pressure, additional void volume is created, thereby reducing the overall pressure inside the containment vessel. However, quantitative data on this structural deformation of the convenience cans has not been measured, and repeatability of the deformation is not predictable. Therefore, convenience can geometry is assumed not to change for the calculation of pressure inside the containment vessel.

Table 3.11. Total pressure inside the containment vessel at 123.85°C (254.93°F) [a]

CVA	n_{MNOP} (lb-mole)	n_{po} (lb-mole)	n_{bo} (lb-mole)	n_T (lb-mole)	P_T (psia)
1	3.8549e-04	1.3458e-05	3.1529e-04	7.1424e-04	43.852
2	3.9060e-04	1.9225e-05	3.1529e-04	7.2512e-04	43.938
3	3.9976e-04	1.1535e-05	3.1529e-04	7.2659e-04	43.018
4	3.6547e-04	7.6901e-06	3.1529e-04	6.8845e-04	44.585
5	8.4143e-05	0.0000e+00	0.0000e+00	8.4143e-05	23.668
6	2.9004e-04	0.0000e+00	3.1529e-04	6.0533e-04	19.396

[a] This assumes that the convenience cans, polyethylene bottles, and Cat 277-4 spacer cans are sealed.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

3.2.1 Material properties

Thermal properties at various temperatures for the stainless steel used in the fabrication of the drum, noncombustible cast refractory (Kaolite 1600), noncombustible neutron poison (BoroBond 4 or Cat 277-4), silicone rubber pads, and air are listed in Table 3.12. Properties used to evaluate thermal stresses due to differences in coefficient of thermal expansion are listed in Table 3.13.

3.2.2 Component Specifications

Component specifications are listed in Tables 3.14 and 3.15.

3.3 GENERAL CONSIDERATIONS

Thermal evaluation of the package design for NCT was performed by analysis. Evaluation of the package design for HAC was performed by a combination of testing and analysis.

3.3.1 Evaluation by Analysis

A description of the method and calculations used to perform the thermal and thermal stress analyses of the package for NCT and HAC is presented in detail in Appendices 3.6.1, 3.6.2 and 3.6.3.

Fig. 3.4. Test unit removal from furnace.

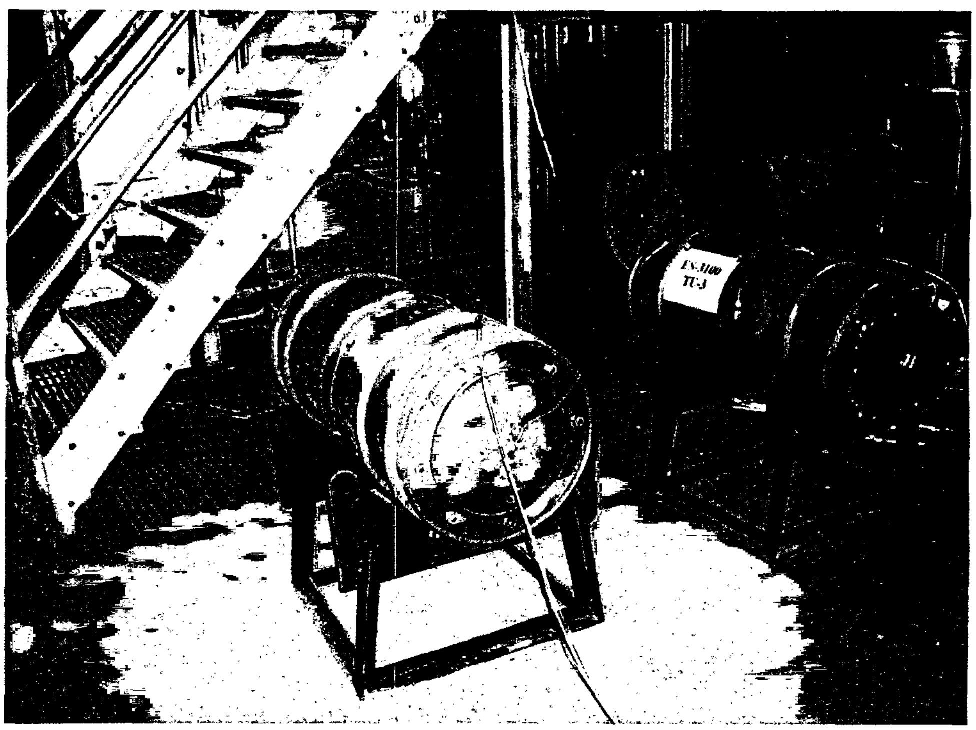


Fig. 3.5. Test unit cool down and monitoring arrangement.

Table 3.16. Summary of results of evaluation for the ES-3100 under NCT

Conditions	Calculated results	Allowable limit	SARP reference
Minimum package temperature, °C (°F)	-40 (-40)	-40 (-40)	Sect. 3.4.1
Maximum drum assembly stress due to cold conditions per 10 CFR 71.71(c)(2), kPa (psia)	61,150 (8,869)	132,379 (19,200)	Appendix 3.6.3
Minimum containment vessel pressure, kPa (psia)	76.74 (11.13)	0.0 (0.0)	Sect. 3.4.1
Maximum drum temperature with insolation, °C (°F)	117.72 (243.89)[a]	N/A	Appendix 3.6.2 Sect. 3.4.1
Maximum drum assembly stress due to hot conditions per 10 CFR 71.71(c)(1), kPa (psia)	66,934 (9,708)	132,379 (19,200)	Appendix 3.6.3
Containment vessel temperature with insolation, °C (°F)	87.81 (190.06)[a]	427 (800)[b]	Appendix 3.6.2 Sect. 3.4.1
Maximum O-ring temperature, °C (°F)	87.81 (190.06)	150 (302)[c]	Appendix 3.6.2 Sect. 3.4.1
Maximum containment vessel pressure, kPa (psia)	122.63 (17.786)[d]	801.2 (116.2)[e]	Appendix 3.6.4 Sect. 3.4.2

[a] Appendix 3.6.2.
[b] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[c] Maximum O-ring seal life up to 150°C (302°F) for continuous service (*Parker O-ring Handbook*, Fig. 2-24).
[d] Appendix 3.6.4.
[e] Appendix 2.10.1 allowable limit.

Table 3.17. Summary of results of evaluation under HAC for the ES-3100 shipping arrangement using bounding case parameters

Condition	Results	Design limits	SARP references
Maximum adjusted containment vessel temperature during testing, °C (°F)	152.22 (306.00)	426.67 (800)[a]	Sect. 3.5.3
Maximum containment vessel pressure during testing, kPa (psia)	340.57 (49.396)	801.2 (116.2)[b]	Appendix 3.6.5 Sect. 3.5.3
Maximum adjusted O-ring temperature, °C (°F)	141.22 (286.20)	150 (302)[c]	Sect. 3.5.3

[a] *ASME Boiler and Pressure Code*, Sect. II, Part D, maximum allowable temperature for Sect. III, Div. 1, Subsection NB vessel.
[b] Appendix 2.10.1 at 148.89°C (300°F).
[c] Continuous service limit (B&PVC, Sect. III).

time at a temperature approaching −40°C (−40°F). The package has been examined for use at −40°C (−40°F) (Sect. 2.6.2). No detrimental effects on the package structure or sealing capability result from this minimum temperature requirement. The normal service temperature range of the O-rings used in the containment boundary is −40 to 150°C (−40 to 302°F), in accordance with the *Parker O-ring Handbook*; thus, the seal will not be affected by this minimum package temperature in accordance with 10 CFR 71.71(c)(2). Leak testing conducted on Test Unit-2 to the leak tight criteria stipulated by ANSI N14.5-1997 following compliance testing provides justification of the above statements.

3.4.2 Maximum Normal Operating Pressure

The stainless-steel drum and cast refractory system will not pressurize as a result of temperature increases because of four ventilation holes (0.795 cm [0.313 in.] in diameter) drilled in the drum side wall 3.81 cm (1.5 in.) from the flanged top and equally spaced around the drum. The holes are filled with nylon plugs, but they are not hermetically sealed. The inner liner encapsulating the noncombustible neutron poison (Cat 277-4) will not pressurize as a result of temperature increases because of three ventilation holes (0.635 cm [0.25 in.] in diameter) and a slot (1.63 cm [0.64 in.] in width and 4.17 cm [1.64 in.] in length) drilled into this inner liner. These features are covered during transport with aluminum tape to prevent contamination of the neutron poison. This tape does not represent a hermetic seal.

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 one 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 for the most restrictive containment vessel configurations. For conservatism, the decay heat of 0.4 W was used for the maximum internal heat load in evaluating the package for NCT. The maximum calculated internal absolute pressure in the containment vessel with solar insolation and the bounding case parameters is 122.63 kPa (17.786 psia). This pressure incorporated the off-gassing from the silicone rubber pads, polyethylene bottles, and polyethylene bagging and assumes that the containment vessel is assembled at ambient temperature and pressure at 100% relative humidity. The heat-transfer capability of the packaging is not degraded due to gap creation caused by differences in the fabrication material's coefficient of thermal expansion. Modeling assumed nominal gaps and position based on the engineering drawings of Appendix 1.4.8.

Little or no hydrogen gas is generated inside the containment vessel due to thermal- or radiation-induced decomposition of the water vapor, or polyethylene bagging or bottles.

3.4.3 Maximum Thermal Stresses

The temperature of the package under NCT will vary from a low of −40°C (−40°F) throughout the package to a maximum of 117.72 and 87.81°C (243.89 and 190.06°F) (Appendix 3.6.2) on the surface of the drum and the containment vessel, respectively (Sect. 3.4.1). The slow temperature increase or decrease experienced in normal conditions between these limits will result in an essentially uniform temperature change throughout the package. All materials of construction are within this operating temperature range (Table 3.15). Thermal stresses due to differences in thermal expansion are insignificant, as discussed in Sects. 2.6.1.2 and 2.6.2.

Most of the components of the packaging are completely unrestrained. Therefore, any thermal stresses in the packaging components as the temperature varies between the extremes listed above will have no effect on the ability of the packaging to maintain containment, shielding integrity, and nuclear subcriticality. The maximum stresses due to pressure under NCT for the containment vessel are given in Tables 2.21 and 2.22. These values are significantly below the allowable stresses for the packaging components. 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). This situation produces a zero gap between the these materials and the bounding drum and inner liners. Due to differences in coefficients of thermal expansion, some radial and axial interference is expected due to thermal growth or contraction of the inner liners. These radial and axial interferences and induced stresses are calculated in Appendix 3.6.3. The results show that the stresses induced are minimal and do not reduce the effectiveness of the drum assembly.

The containment vessel, which is Type 304L austenitic (iron-nickel-chromium) stainless steel, is designed and fabricated in accordance with Sects. III Subsect. NB and IX of the *ASME Boiler and Pressure Vessel Code* (B&PVC Sect. III and B&PVC Sect. IX). The two sealing surfaces of each containment boundary are joined together by torquing the closure nut inside the containment vessel body to 162.7 ±6.8 N·m (120 ±5 lbf-ft). The O-ring material is ethylene-propylene elastomer.

The design temperature range of the containment vessel is −29 to 148.89°C (−20 to 300°F) (Appendix 2.10.1). However, the package has been evaluated to −40°C (−40°F) (Sect. 2.6.2). The thermal properties of the stainless-steel container body, lid, and closure nut are not critical at these temperatures. The O-ring seal is important for the containment properties of the containment vessel. The normal service temperature range for the elastomer O-ring is −40 to 150°C (−40 to 302°F) for continuous service and up to 165°C (329°F) for 72 h (*Parker O-ring Handbook*). The maximum adjusted HAC temperature of the ES-3100 containment vessel was based upon the thermal testing results in the vicinity of the O-rings. The maximum temperature recorded in the vicinity of the ES-3100 O-rings (241°F) is shown in Table 3.9. As shown in Sect. 3.5.3, the maximum temperature for the containment vessel at the O-ring location was adjusted for the ES-3100 package to 141.22°C (286.20°F). Hence, no damage would be expected to the O-rings during HAC.

The test packages were all preheated to above 38°C (100°F) prior to being placed in the furnace, which was heated to over 800°C (1475°F). As noted in the test report (Appendix 2.10.7), 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 3.9). 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 B&PVC, Sect. III. Thermal stress is defined as a self-balancing stress produced by a nonuniform distribution of temperature (Paragraph NB-3213.13 of B&PVC, Sect. III). 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 (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). 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 (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.

Following the thermal test, the volume between the O-rings on the five containment vessels (Sect. 2.7.4) was then leak tested and met the air leak-rate criterion of 10^{-4} ref-cm^3/s. Following the O-ring leak check, the five containment vessels were drilled and tapped for full body helium leak testing. All five containment vessels passed the leak rate criteria for leaktightness per ANSI N14.5-1997. The containment

Table 3.21 shows the results of adding the eight temperature adjustments previously discussed to the black-out temperatures for the containment vessel with the 3.6-kg (8-lb) mock-up (Test Unit-5). These adjusted temperatures would not adversely affect the stainless-steel components or the O-ring materials of the containment vessel.

Table 3.21. Predicted temperatures of the containment vessel due to HAC (°F)

Node [a]	Analytical temperature adjustments (°F)	Maximum blackout temperature on Test Unit-5 (°F)	Final predicted CV temperature (°F)
6715	45.00	261	306.00
6359	45.20	241	286.20
6574	50.20	199	249.20
6399	44.90	210	254.90

[a] See Figs. 8 through 11 in Appendix 3.6.2 for details of node locations.

To determine the maximum pressure inside the containment vessel as a result of thermal testing, the average adjusted gas temperature must be calculated based on the above results. The approach used is to divide the containment vessel volume into three distinct equal regions and then average the three together. The first volume is represented by the gas adjacent to the containment vessel lid and flange region and the top convenience can. Based on the temperature recorded near the O-rings [116.11°C (241°F)] and the temperature recorded on the external surface of the convenience can [98.89°C (210°F)], the average temperature of the gas in this region is 107.50°C (225.50°F). Using the temperature adjustment of 25.11°C (45.20°F) for this region, the adjusted average temperature in the first region is 132.61°C (270.70°F). The second volume is represented by the gas adjacent to the second convenience can from the top. Based on the temperature recorded on the containment vessel wall and convenience can [92.78°C (199°F)], the average temperature of gas in this region is 92.78°C (199°F). Using the temperature adjustment of 27.89°C (50.20°F) for this region, the adjusted average temperature in the second region is 120.67°C (249.20°F). The third and final volume is represented by the gas adjacent to the bottom convenience can. Again based on the convenience can temperature [87.78°C (190°F)] and the containment vessel end cap temperature [98.89°C (210°F)], the average temperature of gas in this region is 93.33°C (200°F). Using the temperature adjustment of 24.94°C (44.90°F) for this region, the adjusted average temperature in the third region is 118.28°C (244.90°F). Averaging these three temperatures, an average adjusted gas temperature of 123.85°C (254.93°F) is determined for the containment vessel.

As shown in Appendix 3.6.5, the maximum adjusted average gas temperature and pressure in the containment vessel during accident conditions was calculated to be 123.85°C (254.93°F), and [redacted] respectively.

The maximum adjusted temperature on the surface of the containment vessel, adjacent to the O-rings, visible inside the containment vessel following the 0.9-m (3-ft) water immersion test or the 15-m (50-ft) water immersion test on Test Unit-6.

The ES-3100 package satisfies the requirements of 10 CFR 71.73 for transport of the 36-kg (79.37-lb) arrangements shown in Table 2.8. Section 2.7 has additional details to support this conclusion.

3.5.4 Accident Conditions for Fissile Material Packages for Air Transport

This section is not applicable.

APPENDIX 3.6.4

CONTAINMENT VESSEL PRESSURE DUE TO NORMAL CONDITIONS OF TRANSPORT FOR THE PROPOSED CONTENTS

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APPENDIX 3.6.4

CONTAINMENT VESSEL PRESSURE DUE TO NORMAL CONDITIONS OF TRANSPORT FOR THE PROPOSED CONTENTS

The following calculations determine the pressure of the containment vessel when subjected to the tests and conditions of Normal Condition of Transport per 10 CFR 71.71 for the most restrictive convenience can arrangements shipped in the ES-3100. The following packaging arrangements are evaluated for shipment:

1. one shipment will contain six cans with external dimensions of 4.25 in. diameter by 4.875 in. high; this configuration bounds six cans with external dimensions of 3.00 in. diameter by 4.75 in. high;

2. one shipment will contain five cans with external dimensions of 4.25 in. diameter by 4.875 in. high and three can spacers, top can will be empty;

3. one shipment will contain three cans with external dimension of 4.25 in. diameter by 8.75 in. high and two can spacers;

4. one shipment will contain three cans with external dimension of 4.25 in. diameter by 10 in. high; and

5. one shipment will contain three cans with external dimension of 5.00 in. diameter by 10 in. high. [Analyzed, but not used.]

6. one shipment will contain three polyethylene bottles with external dimensions of 4.94 in. diameter by 8.7 in. high.

To determine this pressure, the following assumptions have been made:

1. The HEU contents are loaded into convenience cans which are placed inside the ES-3100 containment vessel at standard temperature (T_{amb}) and pressure (P_t) (77°F and 14.7 psia) with air at a maximum relative humidity of 100%.

2. The convenience cans are assumed to be sealed, which minimizes the void volume inside the containment vessel.

3. Polyethylene bagging of contents and/or convenience cans is limited to 500 g per containment vessel shipping arrangement.

4. ~~No contents that will off-gas due to temperatures above ambient can be used inside the containment vessel when convenience cans are greater than 10.80 cm (4.25 in.) in diameter.~~

5. For polyethylene bottle configurations, total polyethylene bagging and bottle weight is limited to 500 g per containment vessel.

Applying Dalton's law concerning a mixture of gases, the properties of each component are considered as though each component exists separately at the volume and temperature of the mixture. Therefore, the molar quantities of each constituent inside the containment vessel (i.e., dry air, water vapor, polyethylene bagging, and silicone rubber) must be calculated individually.

To calculate these molar properties, the void volume of the containment vessel must be determined. The volume inside an empty ES-3100 containment vessel was determined from Algor finite element software to be 637.18 in.^{3} (10,441.51 cm^3).

I. Molar quantity determination for dry air and water vapor

According to *Fundamentals of Classical Thermodynamics*,

"Relative humidity (Φ) is defined as the ratio of the mole fraction in the mixture to the mole fraction of vapor in a saturated mixture at the same temperature and total pressure."

Since the vapor is considered an ideal gas, the definition reduces to the ratio of the partial pressure of the vapor (P_v) as it exists in the mixture to the saturation pressure of the vapor (P_g) at the same temperature.

Therefore,

$$\Phi = P_v / P_g .$$

From the above equation and interpolating the values given in Table A.1.1 of *Fundamentals of Classical Thermodynamics*, the partial pressure of the water vapor at saturation is:

$$P_v = 1.0\,(0.464)\text{ psia,}$$
$$P_v = 0.464\text{ psia.}$$

The partial pressure of the dry air (P_a) in the volume:

$$P_a = P_t - P_v = 14.7 - 0.464 = 14.236\text{ psia.}$$

From the ideal gas law, the number of water vapor moles and dry air moles in the void volume (V_V) for each containment vessel arrangement (CVA) is calculated as follows:

$$n_v = \frac{P_v \cdot V_v}{R_u \cdot T_{amb} \cdot 12}, \quad n_a = \frac{P_a \cdot V_v}{R_u \cdot T_{amb} \cdot 12}$$

To determine the number of moles, the void volume of the air mixture must be determined. The void volume (V_V) in the containment vessel for each CVA is calculated as follows:

$$V_V = V_{ECV} - V_{SP} - V_{PB} - V_{CC} - V_{CS} - V_{CH},$$

where

V_{ECV} = volume inside an empty containment vessel,
V_{SP} = silicone pad volume,
V_{PB} = polyethylene bagging volume,
V_{CC} = external volume of the convenience cans or bottles,
V_{CS} = external volume of the can spacers,
V_{CH} = external volume of the convenience can handles.

A summary for each CVA is shown in Table 1.

Table 1. Containment vessel void volume for each CVA

CVA		V_{ECV} (in.^{3})	V_{SP} [a] (in.^{3})	V_{PB} (in.^{3})	V_{CC} (in.^{3})	V_{CS} (in.^{3})	V_{CH} (in.^{3})	V_V (in.^{3})
1	Six 4.875-in.-high cans Seven silicone pads Six can handles	637.18	9.35	30.51	380.47	0.00	1.02	215.83
2	Five 4.875-high cans Nine silicone pads Three Cat 277-4 spacers Eight can handles	637.18	12.03	30.51	317.06	60.60	1.36	215.62
3	Three 8.75-in.- high cans Two Cat 277-4 spacers Six silicone pads Five can handles	637.18	8.02	30.51	345.96	40.40	0.85	211.44
4	Three 10-in.-high cans Four silicone pads Three can handles	637.18	5.35	30.51	396.20	0.00	0.51	204.62
5	Three 10-in.-high cans with can diameters of 5 in.	637.18	0.00	0.00	589.05	0.00	1.02	47.11
6	Three 4.94 in. OD polyethylene bottles	637.18	0.00	9.46	465.33	0.00	0.00	162.39

[a] These volumes are calculated from the weights shown on the engineering drawings and nominal material densities.

Using the above molar equations, the number of moles for water vapor and dry air in the vessel for each CVA is summarized in Table 2.

Table 2. Water vapor and dry air molar summary for each CVA

CVA	P_a (psia)	P_v (psia)	V_V (in.^{3})	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_v (lb-mole)	n_a (lb-mole)
1	14.24	0.464	215.83	1545.32	537	1.0057e-05	3.0855e-04
2	14.24	0.464	215.63	1545.32	537	1.0047e-05	3.0826e-04
3	14.24	0.464	211.44	1545.32	537	9.8522e-06	3.0227e-04
4	14.24	0.464	204.62	1545.32	537	9.5344e-06	2.9252e-04
5	14.24	0.464	47.11	1545.32	537	2.1951e-06	6.7348e-05
6	14.24	0.464	162.39	1545.32	537	7.5666e-06	2.3215e-04

II. Molar quantity determination due to off-gassing for each containment vessel arrangement

The maximum temperature calculated for the containment vessel is 87.81°C (190.06°F). This temperature is assumed to be constant throughout the containment vessel and contents. Therefore, the polyethylene bags and silicone rubber can pads are assumed to be at this temperature.

Using the above calculated results and the specific gas generation of polyethylene bags and silicone rubber pad measurements at temperatures up to 500°F conducted by the Y-12 Development Division, the amount of gas (V_{bo} and V_{po}) generated due to off-gassing of the polyethylene bags and silicone rubber can pads at any temperature is estimated by first determining the off-gassing volume per unit mass at temperature and multiplying that by the total mass of the bags and can supports inside the containment vessel. Based on testing at a temperature of 93.33°C (200°F), no recordable off-gassing occurred in the polyethylene bags or silicone rubber pad material as documented in Appendix 2.10.4. This value was used to determine the off-gassing volume as shown below:

$$V_{po} = W_p \times 0.0 / 16.387 \text{ (in.}^3\text{)}$$

$$V_{bo} = W_b \times 0.0 / 16.387 \text{ (in.}^3\text{)}$$

From the ideal gas law, the number of gas moles in the volume at standard temperature and pressure is as follows:

$$n_{io} = \frac{P_V \cdot V_i}{R_u \cdot T_{amb} \cdot 12}$$

A summary of the results obtained using the above equations for each containment vessel arrangement is presented in Tables 3 and 4.

Table 3. Molar quantity of gas generated due to the silicone rubber pad off-gassing

CVA	W_p (g)	V_{po} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_{po} (lb-mole)
1	186.74	0.00	14.7	1545.32	537	0.0000e+00
2	240.09	0.00	14.7	1545.32	537	0.0000e+00
3	160.06	0.00	14.7	1545.32	537	0.0000e+00
4	106.71	0.00	14.7	1545.32	537	0.0000e+00
5	0.00	0.00	14.7	1545.32	537	0.0000e+00
6	0.00	0.00	14.7	1545.32	537	0.0000e+00

Table 4. Molar quantity of gas generated due to the polyethylene bag and bottle off-gassing

CVA	W_b (g)	V_{bo} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_{bo} (lb-mole)
1	500.00	0.00	14.7	1545.32	537	0.0000e+00
2	500.00	0.00	14.7	1545.32	537	0.0000e+00
3	500.00	0.00	14.7	1545.32	537	0.0000e+00
4	500.00	0.00	14.7	1545.32	537	0.0000e+00
5	0.00	0.00	14.7	1545.32	537	0.0000e+00
6	500.00	0.00	14.7	1545.32	537	0.0000e+00

III. Total pressure due to off-gassing and NCT temperatures inside the containment vessel

The total pressure of the mixture at 87.81°C (190.06°F), P_T, for each containment vessel arrangement is the sum of each of the previously calculated molar quantities. Table 5 summarizes the molar constituents and total pressure of each containment vessel arrangement. The following equation is used to calculated the final containment vessel pressure:

$$P_{87.81°C} = \left(\sum n_i \cdot R \cdot T_{87.81°C} \cdot 12 \right) / V_{GMV},$$

where

n_i = individual molar quantity for each gas,
T = average gas temperature = 87.81°C (190.06°F),
V_{GMV} = V_v = gas mixture volume.

Table 5. Total pressure inside the containment vessel at 87.81°C (190.06°F) [a]

CVA	n_a (lb-mole)	n_v (lb-mole)	n_{po} (lb-mole)	n_{bo} (lb-mole)	n_T (lb-mole)	P_T (psia)
1	3.0855e-04	1.0057e-05	0.0000e+00	0.0000e+00	3.1861e-04	17.786
2	3.0826e-04	1.0047e-05	0.0000e+00	0.0000e+00	3.1831e-04	17.786
3	3.0227e-04	9.8522e-06	0.0000e+00	0.0000e+00	3.1212e-04	17.786
4	2.9252e-04	9.5344e-06	0.0000e+00	0.0000e+00	3.0205e-04	17.786
5	6.7348e-05	2.1951e-06	0.0000e+00	0.0000e+00	6.9543e-05	17.786
6	2.3215e-04	7.5666e-06	0.0000e+00	0.0000e+00	2.3972e-04	17.786

[a] This assumes that the internal convenience cans, polyethylene bottles, and Cat 277-4 spacer cans are sealed.

At −40°C (−40°F), the partial pressure of the water vapor is conservatively assumed to be zero. Therefore, the final pressure of the mixture at −40°C (−40°F) is calculated according to the ideal gas law based solely on the partial pressure of the air.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2},$$

where

P_1 = 14.236 psi,
T_1 = 77°F = 536.67 R,
T_2 = −40°F = 419.67 R,
V_1 = V_2.

Rearranging and solving for P_2,

P_2 = $P_1 (T_2/T_1)$,
P_2 = (14.236)(419.67/536.67) = 11.13 psia.

APPENDIX 3.6.5

CONTAINMENT VESSEL PRESSURE DUE TO HYPOTHETICAL ACCIDENT CONDITIONS FOR THE PROPOSED CONTENTS

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APPENDIX 3.6.5

CONTAINMENT VESSEL PRESSURE DUE TO HYPOTHETICAL ACCIDENT CONDITIONS FOR THE PROPOSED CONTENTS

The following calculations determine the pressure of the containment vessel when subjected to the tests and conditions of Hypothetical Accident Conditions per 10 CFR 71.73 for the most restrictive convenience can arrangements shipped in the ES-3100 package. The following packaging arrangements are evaluated for shipment:

1. one shipment will contain six cans with external dimensions of 4.25 in. diam by 4.875 in. high; this configuration bounds six cans with external dimensions of 3.00 in. diameter by 8.75 in. high;

2. one shipment will contain five cans with external dimensions of 4.25 in. diam by 4.875 in. high and three can spacers, the top can is empty;

3. one shipment will contain three cans with external dimensions of 4.25 in. diam by 8.75 in. high and 2 can spacers;

4. one shipment will contain three cans with external dimensions of 4.25 in. diam by 10 in. high; and

5. one shipment will contain three cans with external dimensions of 5.00 in. diam by 10 in. high. [Analyzed, but not used.]

6. one shipment will contain three polyethylene bottles with external dimensions of 4.94 in. diameter by 8.7 in. high.

To determine this pressure, the following assumptions have been made:

1. The highly enriched uranium (HEU) contents are loaded into convenience cans and placed inside the ES-3100 containment vessel at standard temperature (77°F) and at the maximum normal operating pressure (17.786 psia) with air at a maximum relative humidity of 100%.

2. The convenience cans are assumed to be sealed to minimize the void volume inside the containment vessel.

3. Polyethylene bagging of contents and/or convenience cans is limited to 500 g per containment vessel shipping arrangement.

4. ~~No contents that will off-gas due to temperatures above ambient conditions can be used inside the containment vessel when convenience cans are greater than 10.80 cm (4.25 in.) in diameter.~~

5. For polyethylene bottle configuration, total polyethylene bagging and bottles weight limited to 500 g per containment vessel.

Applying Dalton's law concerning a mixture of gases, the properties of each component are considered as though each component exists separately at the volume and temperature of the mixture. Therefore, the molar quantities of each constituent inside the containment vessel (i.e., dry air, water vapor, polyethylene bagging, and silicone rubber) must be calculated individually.

To calculate these molar properties, the void volume of the containment vessel must be determined. The volume inside an empty ES-3100 containment vessel was determined from Algor finite element software to be 637.18 in.^{3} (10,441.51 cm^3).

I. Molar quantity determination based on MNOP

Table 1. Total pressure inside the containment vessel at 87.81°C (190.06°F)[a]

CVA	n_a (lb-mole)	n_v (lb-mole)	n_{po} (lb-mole)	n_{bo} (lb-mole)	n_T (lb-mole)	P_T (psia)
1	3.0855e-04	1.0057e-05	0.0000e+00	0.0000e+00	3.1861e-04	17.786
2	3.0826e-04	1.0047e-05	0.0000e+00	0.0000e+00	3.1831e-04	17.786
3	3.0227e-04	9.8522e-06	0.0000e+00	0.0000e+00	3.1212e-04	17.786
4	2.9252e-04	9.5344e-06	0.0000e+00	0.0000e+00	3.0205e-04	17.786
5	6.7348e-05	2.1951e-06	0.0000e+00	0.0000e+00	6.9543e-05	17.786
6	2.3215e-04	7.5666e-06	0.0000e+00	0.0000e+00	2.3972e-04	17.786

[a] This assumes that the internal convenience cans, polyethylene bottles, and Cat 277-4 spacer cans are sealed.

To use the maximum normal operating pressure at standard temperture, the number of lb-mole of gas needs to be increased using the following equation:

$$n_{MNOP} = \frac{P_T \cdot V_V}{R_u \cdot T_{amb} \cdot 12}$$

Using the above molar equations, the total number of moles is summarized in Table 2.

Table 2. Molar summary at MNOP and 77°F

CVA	P_T (psia)	V_V (in.^{3})	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_{MNOP} (lb-mole)
1	17.786	215.83	1545.32	537	3.8549e-04
2	17.786	215.63	1545.32	537	3.8514e-04
3	17.786	211.44	1545.32	537	3.7765e-04
4	17.786	204.62	1545.32	537	3.6547e-04
5	17.786	47.11	1545.32	537	8.4143e-05
6	17.786	162.39	1545.32	537	2.9004e-04

II. Molar quantity determination due to off-gassing for each containment vessel arrangement

To determine the maximum pressure inside the containment vessel as a result of thermal testing, the average adjusted gas temperature must be calculated based on the results shown in Sect. 3.5.3. The approach used is to divide the containment vessel volume into three distinct equal regions and then average the three together. The first volume is represented by the gas adjacent to the containment vessel lid and flange region and the top most convenience can. Based on the temperature recorded near the O-rings [116.11°C (241°F)] and the temperature recorded on the external surface of the convenience can [98.89°C (210°F)], the average temperature of the gas in this region is 107.50°C (225.50°F). Using the temperature adjustment of 25.11°C (45.20°F) for this region, the adjusted average temperature in the first region is 132.61°C (270.70°F). The second volume is represented by the gas adjacent to the second convenience can from the top. Based on the temperature recorded on the containment vessel wall and convenience can [92.78°C (199°F)], the average temperature of gas in this region is 92.78°C (199°F). Using the temperature adjustment of 27.89°C (50.20°F) for this region, the adjusted average temperature in the second region is 120.67°C (249.20°F). The third and final volume is represented by the gas adjacent to the bottom convenience can. Again, based on the convenience can temperature [87.78°C (190°F)] and the containment vessel end cap temperature [98.89°C (210°F), the average temperature of gas in this region is 93.33°C (200°F). Using the temperature adjustment of 24.94°C (44.90°F) for this region, the adjusted average temperature in the third region is 118.28°C (244.90°F). Averaging these three temperatures, an average adjusted gas temperature of 123.85°C (254.93°F) is determined for the containment vessel.

Using the above calculated results and the specific gas generation of polyethylene bags and silicone rubber pads measurements at temperatures up to 500°F conducted by the Y-12 Development Division (Appendix 2.10.4), the amount of gas generated due to off-gassing of the silicone rubber can pads and the polyethylene bags at 123.85°C (254.93°F), (V_{po} and V_{bo}) is estimated by first determining the off-gassing volume per unit mass at temperature and multiplying that by the total mass of the bags and silicone rubber can supports inside the containment vessel. Based on testing at an approximate temperature of 141.11°C (286.00°F), values of ~7.0 and ~0.8 cm^3 (STP)/g for the polyethylene bagging and silicone rubber pads, respectively, were taken from the curves for the off-gassing volume per unit mass as documented in Appendix 2.10.4. These values are used to determine the off-gassing volume as shown below:

$$V_{po} = W_p \times 0.8 / 16.387 \text{ (in.}^3\text{)},$$

$$V_{bo} = W_b \times 7.0 / 16.387 \text{ (in.}^3\text{)}.$$

From the ideal gas law, the number of gas moles in the volume is as follows:

$$n_i = \frac{P_V \cdot V_i}{R_u \cdot T_{amb} \cdot 12}$$

A summary of the results obtained using the above equations for each containment vessel arrangement is presented in Tables 3 and 4.

Table 3. Molar quantity of gas generated due to the silicone rubber pad off-gassing

CVA	W_p (g)	V_{po} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_{po} (lb-mole)
1	186.74	9.12	14.7	1545.32	537	1.3458e-05
2	240.09	11.72	14.7	1545.32	537	1.7302e-05
3	160.06	7.81	14.7	1545.32	537	1.1535e-05
4	106.71	5.21	14.7	1545.32	537	7.6901e-06
5	0.00	0.00	14.7	1545.32	537	0.0000e+00
6	0.00	0.00	14.7	1545.32	537	0.0000e+00

Table 4. Molar quantity of gas generated due to polyethylene bag and bottle off-gassing

CVA	W_b (g)	V_{bo} (in.^{3})	P_V (psia)	R_u (ft-lb/lb-mole·R)	T_{amb} (R)	n_{bo} (lb-mole)
1	500.00	213.58	14.7	1545.32	537	3.1529e-04
2	500.00	213.58	14.7	1545.32	537	3.1529e-04
3	500.00	213.58	14.7	1545.32	537	3.1529e-04
4	500.00	213.58	14.7	1545.32	537	3.1529e-04
5	0.00	0.00	14.7	1545.32	537	0.0000e+00
6	500.00	213.58	14.7	1545.32	537	3.1529e-04

III. Total pressure due to off-gassing and HAC temperatures inside the containment vessel

The total pressure of the mixture at 123.85°C (254.93°F), P_T, for each containment vessel arrangement is the sum of each of the previously calculated molar quantities. Table 5 summarizes the molar constituents and total pressure of each containment vessel arrangement. The following equation is used to calculated the final containment vessel pressure:

$$P_{123.85°C} = (\sum n_i \cdot R \cdot T \cdot 12) / V_{GMV} ,$$

where

n_i = individual molar quantity for each gas,
T = average gas temperature = 123.85°C (254.93°F),
V_{GMV} = V_v = gas mixture volume.

Table 5. Total pressure inside the containment vessel at 123.85°C (254.93°F) [a]

CVA	n_{MNOP} (lb-mole)	n_{po} (lb-mole)	n_{bo} (lb-mole)	n_T (lb-mole)	P_T (psia)
1	3.8549e-04	1.3458e-05	3.1529e-04	7.1424e-04	43.852
2	3.8514e-04	1.7302e-05	3.1529e-04	7.1966e-04	44.108
3	3.7765e-04	1.1535e-05	3.1529e-04	7.0448e-04	44.151
4	3.6547e-04	7.6901e-06	3.1529e-04	6.8845e-04	44.585
5	8.4143e-05	0.0000e+00	0.0000e+00	8.4143e-05	23.668
6	2.9004e-04	0.0000e+00	3.1529e-04	6.0533e-04	89.396

[a] This assumes that the internal convenience cans, polyethylene bottles, and Cat 277-4 spacer cans are sealed.

Table 4.7. Regulatory leakage criteria for HAC [a]

Verification activity	Fast absorption		Medium absorption		Slow absorption	
	L_{RA-air} (ref-cm^3/s)	L_{RA-He} (cm^3/s)	L_{RA-air} (ref-cm^3/s)	L_{RA-He} (cm^3/s)	L_{RA-air} (ref-cm^3/s)	L_{RA-He} (cm^3/s)
Design	1.0945e+01	1.0448e+01	1.0469e+01	9.9961e+00	9.2843e+00	8.8703e+00

[a] The procedure used to calculate the above criteria is shown in Appendix 4.6.2.

Table 4.8 Containment vessel design verification tests for HAC

Test Type	Test Values	Leakage test procedure
Design and compliance leakage testing		
Design verification of O-ring seal (air)	$L_T \leq 1.0 \times 10^{-4}$ ref-cm^3/s	See Appendix 2.10.7
Design verification of containment vessel boundary (helium)	$L_T \leq 2.0 \times 10^{-7}$ cm^3/s	See Appendix 2.10.7

lid was drilled and tapped for a helium leak-check port. The entire containment boundary was then helium leak checked and passed the leaktight criteria. Also, no visible water was seen inside the inner O-ring groove of Test Unit-6 and no water was observed inside any of the other test units.

To verify the entire containment boundary to the leaktight criteria, the containment vessels of Test Units-1 through -5 were helium leak tested using the procedure shown in the test report (Appendix 2.10.7). These test units had previously been subjected to the drop test stipulated in 10 CFR 71.71 (c)(6) and the sequential tests stipulated in 10 CFR 71.73 except for Test Unit-4, which had been first subjected to the testing in accordance with 10 CFR 71.71. The maximum recorded helium leak rate for any of these containment vessels was 2.0×10^{-7} cm^3/s after 20 min of testing on Test Unit-4 as documented in Section 5.2 of the test report (Appendix 2.10.7). Test Units-2 and -5 displayed some unusual pulsing action during leak testing. The peak amplitude changed after adding helium in a manner expected for diffusion through the O-rings rather than a rise immediately following the addition of helium that would indicate a leak to the outside of the containment vessel. This is further discussed and graphically presented on pages 88 through 91 of the ES-3100 test report (Appendix 2.10.7). These measured leakage rates verify that the containment vessels are leaktight in accordance with ANSI N14.5-1997. Therefore, the containment boundary of the ES-3100 package was maintained during the HAC testing.

The 36 kg of HEU content is unirradiated; therefore, only very small quantities of fission gas products will be produced from spontaneous fission and subcritical neutron induced fission. Fission gas products are produced in such small quantities that they have no measurable effect on the releasable content source term or containment vessel pressurization. Fission gas products will not be considered further in this SAR.

4.5 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

The maximum allowable release of radioactive material allowed by 10 CFR 71.51(a)(2) under HAC is A_2 in one week. Title 10 CFR 71.51(a)(2) also specifies that there be no escape of ^{85}Kr exceeding 10 A_2 in one week. ANSI N14.5-1997 specifies the leakage test methods and leakage rates that are accepted in Nuclear Regulatory Commission (NRC) Regulatory Guide 7.4 as demonstrating that a package meets the 10 CFR 71.51(a)(2) requirements for containment. The containment criteria for the ES-3100 package will be leaktight, defined in ANSI N14.5 paragraph 2.1 as having a leakage rate $\leq 1 \times 10^{-7}$ ref-cm^3/s, during the prototype tests. This leaktight criterion satisfies the design verification requirement stipulated in paragraph 7.2.4 of ANSI N14.5-1997. The requirements of ANSI N14.5-1997 are used for all stages of containment verification for the ES-3100 (i.e., design, fabrication, maintenance, periodic and preshipment). The design, fabrication, maintenance and periodic leakage rate limit is 1×10^{-7} ref-cm^3/s air (or 2.0×10^{-7} cm^3/s helium). The pass criterion for the preshipment leakage rate test, which demonstrates correct assembly of the containment vessels, is 1×10^{-4} ref-cm^3/s, which exceeds the requirements given in ANSI N14.5-1997, paragraph 7.6.4. In accordance with the definition of sensitivity of a leakage test procedure provided in Sections 2 and 7.6.4 of ANSI N14.5-1997, the minimum acceptable leakage rate that the procedure nees to be capable of detecting is 1×10^{-3} ref-cm^3/s. The requirements for the ES-3100 exceed the regulatory criterion by specifying a leakage rate of $\leq 1 \times 10^{-4}$ ref-cm^3/s, and equipment used in accordance with Section 7.6.4 of ANSI N14.5-1997 would not detect this leakage. The preshipment, fabrication, maintenance, and periodic leakage rate tests are required to be conducted on each containment vessel in accordance with ANSI N14.5-1997 and are specified in Chapters 7 and 8. These leakage rates are not dependent on filters or mechanical cooling.

The requirements of ANSI N14.5-1997 are used for all stages of containment verification for the ES-3100; the design (HAC test) leakage rate limit is 1×10^{-7} ref-cm^3/s (which is defined as leaktight in ANSI N14.5-1997). The packaging has been shown to maintain containment before and after prototype testing by leakage tests performed for containment verification to the requirements of ANSI N14.5-1997. Test Unit-4's containment vessel was subjected to both the NCT and HAC tests. Test Units-1 through -5 were subjected to the free drop stipulated in 10 CFR 71.71(c)(7) and to the sequential HAC test stipulated in 10 CFR 71.73. Following these tests, each containment vessel was helium leak tested in accordance with the test plan. Again, the test results verified that the containment vessels were leaktight. Thus, there could be no release of radioactive materials from the containment vessels. These leakage rates are not dependent on filters or mechanical cooling. These measured leakage rates verify that the containment vessels are leaktight in accordance with ANSI N14.5-1997.

Therefore, the ES-3100 package meets the containment criteria as specified in 10 CFR 71.73 for HAC when shipping the proposed 36 kg of HEU in the containment vessel.

APPENDIX 4.6.2

CALCULATION OF THE ES-3100 CONTAINMENT VESSEL'S REGULATORY REFERENCE AIR LEAKAGE RATES

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maximum NCT gas temperature of 87.81°C (190.06°F) [100°F with solar insolation] and a maximum adjusted HAC gas temperature of 123.85°C (254.93°F).

The following analysis determines the maximum allowable O-ring seal air reference leakage rate for both NCT and HAC. The ANSI N14.5-1997 recommended method using a straight circular tube to model the leakage path is applied. Using this "standard" leakage hole model permits the calculation of equivalent reference leakage rates from which leak-test requirements can be established. Viscosity data for air and helium used in the following analyses were obtained from curve fitting routines at specific temperatures based on viscosity data for air (Handbook of Chemistry and Physics, 55th ed.) and helium (NBS Technical Note 631).

L_N and L_A correspond to the upstream volumetric leakage rate (L_u) at the upstream pressure (P_u).

$L_N = 3.8310 \times 10^{-3}$ cm³/s,
$L_A = 2.2738 \times 10^{1}$ cm³/s.

Find the maximum pressure and temperature in the containment vessel:

Converting the temperature to degrees Kelvin:

$T = 273.15 + T(°C)$,
$T = 273.15 + 5 / 9\ (°F - 32)\ (K)$.

T_N	=	$273.15 + 5 / 9\ (190.06°F - 32)\ (K)$,	(Sect. 3.4.1, for T = 190.06°F)
T_N	=	360.961 K.	NCT
T_A	=	$273.15 + 5 / 9\ (254.93°F - 32)\ (K)$,	(Sect. 3.5.3, for T = 254.93°F)
T_A	=	397.000 K.	HAC

Converting the pressures from psia to atmospheres:

P_N	=	P (psia) / 14.696 (psia/atm),	where P is the pressure in Sect. 3.4.2
P_N	=	17.786 (psia) / 14.696 (psia/atm),	NCT
P_N	=	1.2103 atm.	
P_A	=	P (psia) / 14.696 (psia/atm),	where P is the pressure in Sect. 3.5.3
P_A	=	49.396 (psia) / 14.696 (psia/atm),	HAC
P_A	=	3.3612 atm.	

NCT Leakage Hole Diameter for the HEU Content

The following calculations determine the leakage hole diameter that generates the maximum allowable leakage rate during NCT. To keep these calculations conservative, the maximum values for temperature and pressure were used as steady-state conditions for NCT.

Input data for NCT with air fill gas:

L_N	=	3.8310×10^{-3} cm³/s,	Maximum upstream leakage
P_u	=	1.2103 atm,	Upstream pressure = 17.786 psia
P_d	=	0.2382 atm,	Downstream pressure = 3.5 psia, per 10 CFR 71.71(3)
a	=	0.3531 cm,	Leak path length, 0.139-in. O-ring section diameter
T	=	360.96 K,	Fill gas temperature = 190.06°F

μ	=	0.02141 cP,	Viscosity at temperature
M	=	29 g/g-mole.	Molecular weight of fill gas

The average pressure is:

$$P_a = (P_u + P_d)/2,$$
$$= (1.2103 + 0.2382) / 2,$$
$$P_a = 0.7242 \text{ atm.} \quad \text{Average pressure during NCT}$$

According to ANSI N14.5-1997, the flow leakage hole diameter is unknown. Therefore, the mass-like leakage flow rate must be calculated to calculate the average leakage flow rate.

Q is the mass-like leakage for flow using the upstream leakage, L_u, and pressure, P_u:

$$Q = P_u L_u, \quad \text{(Eq. B1)}$$
$$L_u = L_N. \quad \text{NCT leakage}$$

$$Q = (1.2103)(\text{atm})(3.8310 \times 10^{-3})(\text{cm}^3/\text{s}),$$
$$Q = 4.6366 \times 10^{-3} \text{ atm-cm}^3/\text{s}. \quad \text{NCT mass-like leakage rate}$$

$$Q = P_a L_a, \quad \text{(Eq. B1)}$$
$$L_a = Q / P_a = 4.6366 \times 10^{-3} (\text{atm-cm}^3/\text{s}) / (0.7242)(\text{atm}),$$
$$L_a = 6.4022 \times 10^{-3} \text{ cm}^3/\text{s}. \quad \text{NCT average leakage rate}$$

Solve equations B2–B4 from ANSI N14.5-1997:

$$L_a = (F_c + F_m)(P_u - P_d) \text{ cm}^3/\text{s}, \quad \text{(Eq. B2)}$$
$$L_a = (F_c + F_m)(1.2103 - 0.2382),$$
$$L_a = (0.9721)(F_c + F_m) \text{ cm}^3/\text{s}.$$

$$F_c = (2.49 \times 10^6) D^4 / (a\,\mu) (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B3)}$$
$$F_c = (2.49 \times 10^6) D^4 / ((0.3531)(0.02141)),$$
$$F_c = (3.2943 \times 10^8) D^4 \text{ cm}^3/\text{atm-s}.$$

$$F_m = (3.81 \times 10^3) D^3 (T/M)^{.5} / (a\,P_a) (\text{cm}^3/\text{atm-s}), \quad \text{(Eq. B4)}$$
$$F_m = (3.81 \times 10^3) D^3 (360.96/29)^{.5} / ((0.3531)(0.7242)),$$
$$F_m = (5.2571 \times 10^4) D^3 \text{ cm}^3/\text{atm-s}.$$

From the mass-like leakage calculation:

$$L_a = 6.4022 \times 10^{-3} \text{ cm}^3/\text{s}. \quad \text{NCT average leakage rate}$$

Find the leakage hole diameter that sets:

$$L_2 = L_a.$$

Using the equations:

$$L_2 = (0.9721)(F_c + F_m) \text{ cm}^3/\text{s},$$
$$F_c = (3.2943 \times 10^8) D^4 \text{ cm}^3/\text{atm-s},$$
$$F_m = (5.2571 \times 10^4) D^3 \text{ cm}^3/\text{atm-s}.$$

Input data for HAC:

L_A	=	22.738 cm^3/s,	Maximum exit leakage
P_u	=	3.3612 atm,	Upstream pressure = [redacted] psia
P_d	=	1.0 atm,	Downstream pressure
T	=	397.000 K,	Fill gas temperature = 254.93°F
μ	=	0.02297 cP,	Viscosity of air at temperature
M	=	29 g/g-mole,	Molecular weight of air
a	=	0.3531 cm.	Leak path length, 0.139-in. O-ring section diameter

$P_a = (P_u + P_d) / 2$

$\quad = (3.3612 + 1.0) / 2,$ HAC average pressure

$P_a = 2.1806$ atm.

Q is the mass-like leakage for flow using the upstream leakage, L_u, and pressure, P_u:

$Q = P_u L_u,$ (Eq. B1)

$L_u = L_A.$ HAC leakage

$Q = (3.3612)(atm) (22.738)(cm^3/s),$

$Q = 76.4272$ atm-cm^3/s. HAC mass-like leakage rate

$Q = P_a L_a,$ (Eq. B1)

$L_a = Q / P_a$

$\quad = 76.4272 (atm\text{-}cm^3/s) / (2.1806)(atm),$

$L_a = 35.0488$ cm^3/s. HAC average leakage rate

Solve equations B2–B4 from ANSI N14.5-1997:

$L_a = (F_c + F_m) (P_u - P_d) (cm^3/s),$ (Eq. B2)

$L_a = (F_c + F_m) (3.3612 - 1.0),$

$L_a = 2.3612 (F_c + F_m)$ cm^3/s.

$F_c = (2.49 \times 10^6) D^4 / (a \mu) (cm^3/atm\text{-}s),$ (Eq. B3)

$F_c = (2.49 \times 10^6) D^4 / ((0.3531) (0.02297)),$

$F_c = (3.0706 \times 10^8) D^4$ $cm^3/atm\text{-}s$.

$F_m = (3.81 \times 10^3) D^3 (T / M)^{.5} / (a P_a) (cm^3/atm\text{-}s),$ (Eq. B4)

$F_m = (3.81 \times 10^3) D^3 (397.00 / 29)^{.5} / ((0.3531) (2.1806)),$

$F_m = (1.8310 \times 10^4) D^3$ $cm^3/atm\text{-}s$.

From the mass-like leakage calculation:

$L_a = 35.0488$ cm^3/s. HAC average leakage rate

Find the leakage hole diameter that sets:

$L_2 = L_a.$

Using the equations:

$$L_2 = 2.3612\,(F_c + F_m)\ \text{cm}^3/\text{s},$$
$$F_c = (3.0706 \times 10^8)\,D^4\ \text{cm}^3/\text{atm-s},$$
$$F_m = (1.8310 \times 10^4)\,D^3\ \text{cm}^3/\text{atm-s}.$$

To get a better guess on a new D use:

$$D = D_2\,(L_a / L_2)^{0.252}.$$

Now a guess must be made for D_2 to solve Eq. B2 for HAC:

D_2 = 0.01 (cm), and solve for L_a = 35.0488 (cm^3/s). HAC average leakage rate

Diameter	F_c	F_m	L_2	L_a / L_2
1.0000e-02	3.0706e+00	1.8310e-02	7.2935e+00	4.8055e+00
1.4852e-02	1.4942e+01	5.9992e-02	3.5423e+01	9.8944e-01
1.4813e-02	1.4783e+01	5.9512e-02	3.5046e+01	1.0001e+01
1.4813e-02	1.4784e+01	5.9512e-02	3.5049e+01	1.0000e+00

The HAC leakage hole diameter for the HEU oxide content is:

D = 1.4813×10^{-2} cm. HAC diameter

HAC Reference Air Leakage Rate for HEU Content

The leakage hole diameter found for the maximum allowable leakage rate for HAC will be used to determine the reference air leakage rate. O-ring seal leakage testing must assure that no leakage is greater than the leakage generated by the hole diameter D = 1.5282×10^{-2} cm. Therefore, the HAC reference air leakage rate ($L_{R,A}$) must be calculated to determine the acceptable test leakage rate for post-HAC leakage testing.

Input data for HAC reference air leakage rate:

D	=	1.4813×10^{-2} cm,	From the HAC of transport
a	=	0.3531 cm,	Leak path length, 0.139-in. O-ring section diameter
P_u	=	1.0 atm,	Upstream pressure
P_d	=	0.01 atm,	Downstream pressure
T	=	298 K,	Fill gas temperature, 77°F
M	=	29 g/g-mole,	Molecular weight of air
μ	=	0.0185 cP.	Viscosity at temperature

Calculate P_a:

$$P_a = (P_u + P_d) / 2$$
$$= 0.505 \text{ atm.}$$ HAC average pressure

$$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)\ (\text{cm}^3/\text{atm-s}),$$ (Eq. B3)
$$F_c = (2.49 \times 10^6)\,(1.4813 \times 10^{-2})^4 / ((0.3531)(0.0185)),$$
$$F_c = (3.8122 \times 10^8)\,(1.4813 \times 10^{-2})^4,$$
$$F_c = 1.8355 \times 10^1 \text{ cm}^3/\text{atm-s}.$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}),$$ (Eq. B4)
$$F_m = (3.81 \times 10^3)\,(1.4813 \times 10^{-2})^3\,(298 / 29)^{.5} / ((0.3531)(0.505)),$$
$$F_m = (6.8501 \times 10^4)\,(1.4813 \times 10^{-2})^3,$$
$$F_m = 2.2265 \times 10^{-1} \text{ cm}^3/\text{atm-s}.$$

$$L_u = (F_c + F_m)\,(P_u - P_d)\,(P_a / P_u)\ (\text{cm}^3/\text{s}),$$ (Eq. B5)
$$L_u = (1.8355 \times 10^1 + 2.2265 \times 10^{-1})(\text{cm}^3/\text{atm-s})\,(1.0 - 0.01)(\text{atm})\,(0.505 / 1.0),$$
$$L_u = (1.8578 \times 10^1)(\text{cm}^3/\text{atm-s})\,(0.49995)(\text{atm}),$$
$$L_u = 9.2879 \text{ cm}^3/\text{s}.$$

The HAC reference air leakage rate as defined in ANSI N14.5-1997, Sect. B.3, is the upstream leakage in air.

$$L_{RA,Air} = 9.2879 \text{ ref-cm}^3/\text{s}.$$ for HEU oxide content

The same equations can be used to calculate an allowable leakage rate using helium for leak testing.

$$M = 4 \text{ g/g-mole},$$ Molecular weight of helium
$$\mu = 0.0198 \text{ cP}.$$ Viscosity of helium at temperature

$$F_c = (2.49 \times 10^6)\, D^4 / (a\, \mu)\ (\text{cm}^3/\text{atm-s}),$$ (Eq. B3)
$$F_c = (2.49 \times 10^6)\,(1.4813 \times 10^{-2})^4 / ((0.3531)(0.0198)),$$
$$F_c = (3.5619 \times 10^8)\,(1.4813 \times 10^{-2})^4,$$
$$F_c = 1.7150 \times 10^1 \text{ cm}^3/\text{atm-s}.$$

$$F_m = (3.81 \times 10^3)\, D^3\, (T / M)^{0.5} / (a\, P_a)\ (\text{cm}^3/\text{atm-s}),$$ (Eq. B4)
$$F_m = (3.81 \times 10^3)\,(1.4813 \times 10^{-2})^3\,(298 / 4)^{.5} / ((0.3531)(0.505)),$$
$$F_m = (1.8444 \times 10^5)\,(1.4813 \times 10^{-2})^3,$$
$$F_m = 5.9951 \times 10^{-1} \text{ cm}^3/\text{atm-s}.$$

$$L_u = (F_c + F_m)\,(P_u - P_d)\,(P_a / P_u)\ (\text{cm}^3/\text{s}),$$ (Eq. B5)
$$L_u = (1.7150 \times 10^1 + 5.9951 \times 10^{-1})(\text{cm}^3/\text{atm-s})\,(1.0 - 0.01)(\text{atm})\,(0.505 / 1.0),$$
$$L_u = (1.7749 \times 10^1)(\text{cm}^3/\text{atm-s})\,(0.49995)(\text{atm}),$$
$$L_u = 8.8738 \text{ cm}^3/\text{s}.$$

The allowable leakage rate using helium for leak testing for HAC is:

$$L_{RA,He} = 8.8738 \text{ cm}^3/\text{s}.$$ HAC helium test value

Table 1. Regulatory leakage criteria for 36 kg of HEU

Years from fabrication		NCT		HAC	
		L_{RN-air} (ref-cm^3/s)	L_{RN-He} (cm^3/s)	L_{RA-air} (ref-cm^3/s)	L_{RA-He} (cm^3/s)
Fast absorption	0	4.5676e-03	4.8821e-03	1.1035e+01	1.0533e+01
	5	4.5453e-03	4.8590e-03	1.0981e+01	1.0482e+01
	10	4.5421e-03	4.8556e-03	1.0973e+01	1.0475e+01
	20	4.5401e-03	4.8536e-03	1.0968e+01	1.0470e+01
	30	4.5385e-03	4.8519e-03	1.0965e+01	1.0466e+01
	40	4.5367e-03	4.8501e-03	1.0960e+01	1.0462e+01
	50	4.5348e-03	4.8481e-03	1.0956e+01	1.0458e+01
	60	4.5327e-03	4.8459e-03	1.0951e+01	1.0453e+01
	70	4.5305e-03	4.8436e-03	1.0945e+01	1.0448e+01
Medium absorption	0	4.3669e-03	4.6739e-03	1.0550e+01	1.0073e+01
	5	4.3466e-03	4.6528e-03	1.0501e+01	1.0026e+01
	10	4.3437e-03	4.6498e-03	1.0494e+01	1.0020e+01
	20	4.3420e-03	4.6480e-03	1.0490e+01	1.0016e+01
	30	4.3406e-03	4.6465e-03	1.0486e+01	1.0012e+01
	40	4.3391e-03	4.6449e-03	1.0483e+01	1.0009e+01
	50	4.3373e-03	4.6431e-03	1.0479e+01	1.0005e+01
	60	4.3355e-03	4.6412e-03	1.0474e+01	1.0001e+01
	70	4.3335e-03	4.6392e-03	1.0469e+01	9.9961e+00
Slow absorption	0	3.8624e-03	4.1492e-03	9.3309e+00	8.9147e+00
	5	3.8472e-03	4.1334e-03	9.2942e+00	8.8798e+00
	10	3.8455e-03	4.1316e-03	9.2902e+00	8.8760e+00
	20	3.8453e-03	4.1314e-03	9.2897e+00	8.8755e+00
	30	3.8453e-03	4.1314e-03	9.2896e+00	8.8755e+00
	40	3.8450e-03	4.1312e-03	9.2891e+00	8.8749e+00
	50	3.8445e-03	4.1307e-03	9.2879e+00	8.8738e+00
	60	3.8439e-03	4.1300e-03	9.2863e+00	8.8723e+00
	70	3.8430e-03	4.1291e-03	9.2843e+00	8.8703e+00